1962 Yearbook of Astronomy

Editor J. G. PORTER

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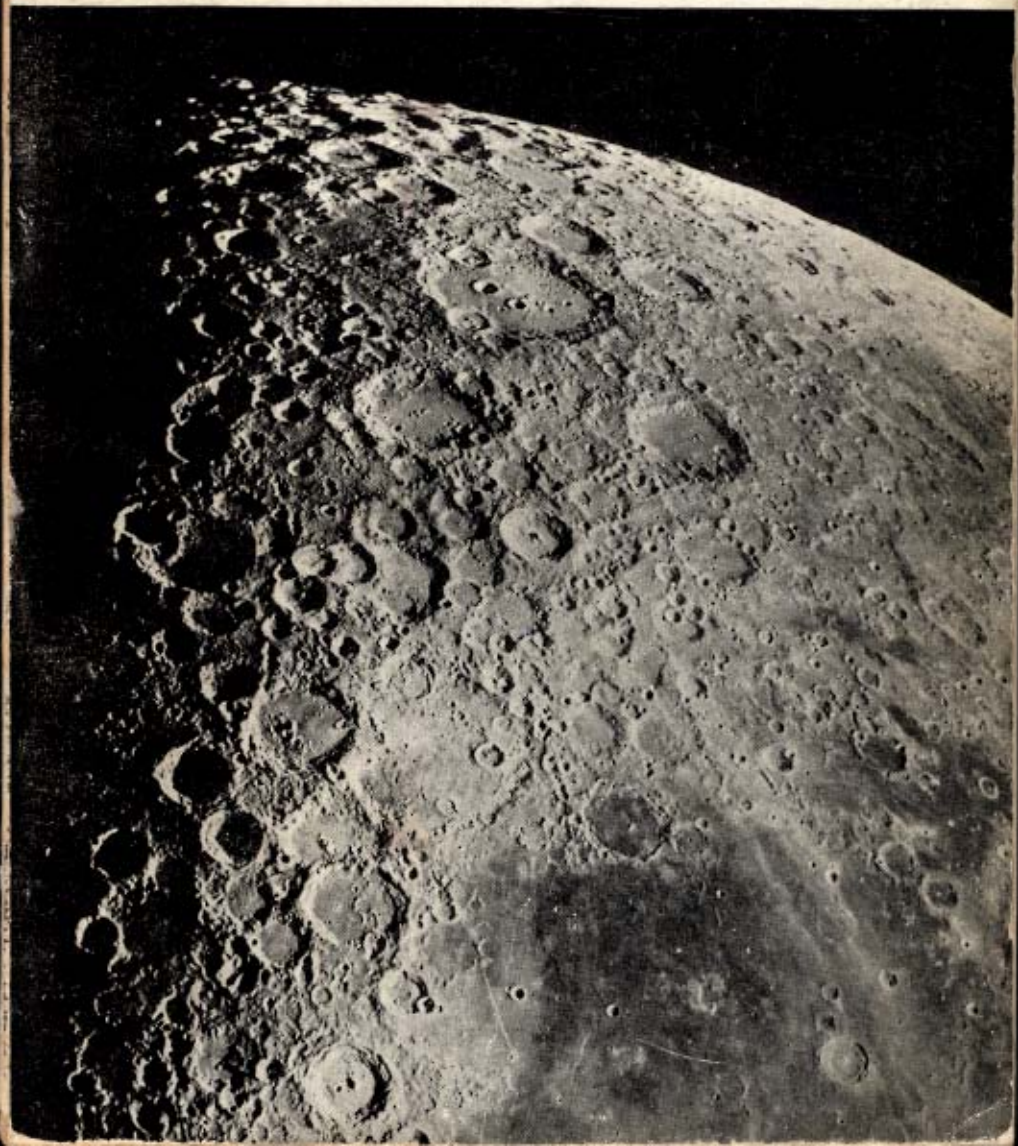

YEARBOOK OF ASTRONOMY 1962

EDITED BY
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Preface

One of the outstanding phenomena of the post-war years has been the tremendous growth of interest in astronomy and space research. Yet there exists in this country no single publication that caters for the popular demand for information on current developments. The *Journal* and *Handbook* of the British Astronomical Association, and the *Memoirs* produced by its various Sections, have somewhat different aims, and the same remark applies to some extent to other Astronomical Societies. There still remains a gap to be filled, and it is the object of this *Yearbook* to meet this need.

The main features of this book are the new star charts on which the positions of the planets may readily be found; the monthly notes describing the movements of the planets and other phenomena; and the articles of topical interest which cover various aspects of research and amateur activities, including a review of the past year's work. No special knowledge of astronomy is called for, and all the astronomical terms used are explained in a separate glossary.

In general, the information is given in descriptive or diagrammatic form, and no attempt has been made to give ephemerides of the planets; indeed, co-ordinates are only given for some objects of special interest, so that they may be found on suitable star maps, such as *Norton's Star Atlas*. Throughout the volume the twenty-four-hour clock is used, time being expressed in G.M.T.; if the star charts are to be used in other countries having the same latitude (e.g., Canada or parts of Europe) then local times must be used, not G.M.T.

Probably a large proportion of the readers of this book will live in towns, where the glare of street lighting makes it impossible

for them to see the night sky at its best, and their interest is necessarily restricted to 'arm-chair astronomy'. It is hoped that this *Yearbook* will appeal as much to these readers as to those who are in a position to use the star charts and other information as a supplement to the tabular matter of the *B.A.A. Handbook*.

Notes on the Star Charts

The stars, together with the Sun, Moon and planets, seem to be set on the surface of the celestial sphere, which appears to rotate about the Earth from east to west. Since it is impossible to represent a curved surface accurately on a plane, any kind of star map is bound to contain some form of distortion. But it is well known that the eye can endure some kinds of distortion better than others, and it is particularly true that the eye is most sensitive to deviations from the vertical and horizontal. For this reason the star charts given in this volume on pages 46 to 49 have been designed to give a true representation of vertical and horizontal lines, whatever may be the resulting distortion in the shape of a constellation figure. It will be found that the amount of distortion is, in general, quite small, and is only obvious in the case of large constellations such as Leo and Pegasus, when these appear at the top of the charts, and so are drawn out sideways.

The charts show all stars down to the fourth magnitude, together with a number of fainter stars which are necessary to define the shape of a constellation. There is no standard system for representing the outlines of the constellations, and triangles and other simple figures have been used to give outlines which are easy to follow with the naked eye. The names of the constellations are given, together with the proper names of the brighter stars. The apparent magnitudes of the stars are indicated roughly by using four different sizes of dots, the larger dots representing the brighter stars.

There are four such charts at each opening, and these give a complete coverage of the sky up to an altitude of $62\frac{1}{2}$ degrees; there are twelve such sets to cover the entire year. The upper two charts show the southern sky, south being at the centre; the coverage is 200 degrees in azimuth, from a little north of east

(top left) to a little north of west (top right). The two lower charts show the northern sky, from a little south of west (lower left) to a little south of east (lower right). There is thus an overlap east and west.

The charts have been drawn for a latitude of 52 degrees, but may be taken without appreciable error to apply to all parts of the British Isles. They will also be equally suitable for any other part of the world having a north latitude of about 52 degrees – e.g., parts of Europe and Asia, and Canada. In such cases the times given must be taken as local time, and not G.M.T., which applies only to the British Isles.

Because the sidereal day is shorter than the solar day, the stars appear to rise and set about four minutes earlier each day, which amounts to two hours in a month. Hence the twelve sets of charts are sufficient to give the appearance of the sky throughout the day at intervals of two hours, or at the same time of night at monthly intervals throughout the year. The actual range of dates and times when the stars on the charts are visible is indicated at the top of each page. This information is summarized in the following table, which gives the number of the star chart to be used for any given month and time.

G.M.T.	16^h	18^h	20^h	22^h	0^h	2^h	4^h	6^h
January	10	11	12	1	2	3	4	5
February		12	1	2	3	4	5	6
March			2	3	4	5	6	
April			3	4	5	6		
May			4	5	6	7		
June			5	6	7			
July			6	7	8	9		
August			7	8	9	10	11	
September		7	8	9	10	11	12	
October		8	9	10	11	12	1	
November	8	9	10	11	12	1	2	3
December	9	10	11	12	1	2	3	4

The charts are drawn to scale, and estimates of altitude and azimuth may be made from them. These values will necessarily be

mere approximations, since no observer will be exactly on the meridian of Greenwich at 52 degrees latitude, but they will generally serve for the identification of stars and planets. The horizontal measurements, marked at every ten degrees, give the azimuths (or true bearings) measured from the north round through east (90 degrees), south (180 degrees), and west (270 degrees). The vertical measurements, similarly marked, give the altitudes of the stars up to 62½ degrees.

The ecliptic is drawn as a broken line on which the longitude is marked at every ten degrees; the positions of the planets at any time are then easily found by reference to the table on page 9.

There is a curious illusion that stars at an altitude of 60 degrees or more are actually overhead, and the beginner may often feel that he is leaning over backwards in trying to see them. These high-altitude stars, being nearer the pole, move more slowly across the sky, and a different kind of map may therefore be used. These overhead stars are given separately on pages 70 and 71, the entire year being covered at one opening. Each of the four maps shows the overhead stars at times which correspond to those of three of the main star charts. The position of the zenith in latitude 52 degrees is indicated by a cross, and this cross also marks the centre of a circle which is 35 degrees from the zenith, and which therefore indicates an altitude of 55 degrees; there is thus a small overlap with the main charts.

The broken line leading from north to south is numbered to indicate the corresponding main chart. Thus on page 70, the N-S line numbered 6 is to be regarded as an extension of the S line of chart 6 on pages 56 and 57, and at the top of these pages are given dates and times which are appropriate.

The scale is the same on all the charts (approximately 25 degrees to the inch), but the overhead stars are plotted as a true map on a conical projection, and are not simple graphs like the main charts.

The Planets and the Ecliptic

The paths of the planets about the Sun all lie close to the plane of the ecliptic, which is marked for us in the sky by the apparent path of the Sun among the stars, and is shown on the star charts by a broken line. The Moon and planets will always be found close to this line, never departing from it by more than about 7 degrees. Thus the planets are most favourably placed for observation when the ecliptic is well displayed, and this means that it should be as high in the sky as possible. This avoids the difficulty of finding a clear horizon, and also overcomes the problem of atmospheric absorption, which greatly reduces the light of the stars. Thus a star at an altitude of 10 degrees suffers a loss of 60 per cent of its light, which corresponds to a whole magnitude; at an altitude of only 4 degrees, the loss may amount to two magnitudes.

The position of the ecliptic in the sky is therefore of great importance, and since it is tilted at about $23\frac{1}{2}$ degrees to the equator, it is only at certain times of the day or year that it is displayed to the best advantage. It will be realized that the Sun (and therefore the ecliptic) is at its highest in the sky at noon in midsummer, and at its lowest at noon in midwinter. Allowing for the daily motion of the sky, these times lead to the fact that the ecliptic is highest at midnight in winter, at sunset in the spring, at noon in summer, and at sunrise in the autumn. Hence these are the best times to see the planets. Thus, if Venus is an evening star, in the western sky after sunset, it will be seen to best advantage if this occurs in the spring, when the ecliptic is high in the sky and slopes down steeply to the north-west. This means that the planet is not only higher in the sky, but will remain for a much longer period above the horizon. For similar reasons, a morning star will be seen at its best on autumn mornings before sunrise, when the ecliptic is high in the east. The outer planets, which can come to opposition and are then in the south at midnight, are best seen when opposition occurs in the winter months. Clearly the summer is the least favourable time to observe the planets, for the ecliptic is always low in the sky on summer nights.

Notes on the Planets in the monthly diagrams

The following general notes on observing the planets are followed by detailed month-by-month accounts of the behaviour of the planets, and of other interesting phenomena. These monthly notes include diagrams of the planetary orbits, and of the apparent movements of the planets at favourable times of the year. Additional notes on other astronomical phenomena will be found on the pages following the star charts.

The monthly diagrams of the orbits of the planets are intended to give a picture of the way in which the planets move about the Sun during the month. These diagrams are similar to those that were given many years ago in the old *English Mechanic*, and which were also adopted for some time in the *Journal* of the B.A.A. The motions of the planets are all anti-clockwise, and the movement during the month is indicated by the thickened line; the longitudes are measured from the Equinox, marked 0°. It is difficult to show all the orbits to scale, since the distance of Pluto from the Sun is about a hundred times that of Mercury. For this reason, only the orbits of the inner planets (Mercury to Mars) are shown to scale, those of the outer planets being merely suggested in the diagrams. A line drawn from the Earth to any other planet will give a rough idea of the apparent longitude of that body, but a more accurate value can be obtained from the table on page 9, and this will enable the position of the planet to be found on the monthly star-charts.

The inferior planets, Mercury and Venus, move in smaller orbits than that of the Earth, and so are always seen near the Sun. They are most obvious at the times of greatest angular distance from the Sun (greatest elongation), which may reach 28 degrees for Mercury, or 47 degrees for Venus. They are then seen as evening stars in the western sky after sunset (at eastern elongations) or as morning stars in the eastern sky before sunrise (at western elongations). The succession of phenomena, conjunctions and elongations, always follows the same order, but the intervals

between them are not equal. Thus if either planet is moving round the far side of its orbit its motion will be to the east, in the same direction in which the Sun appears to be moving. It therefore takes much longer for the planet to overtake the Sun – that is, to come to superior conjunction – than it does when moving round to inferior conjunction, between Sun and Earth. The intervals given in the following table are average values; they remain fairly constant in the case of Venus, which travels in an almost circular orbit. In the case of Mercury, however, conditions vary widely because of the great eccentricity and inclination of the planet's orbit.

			Mercury	*Venus*
Inferior conj.	to	Elongation West	22 days	72 days
Elongation West	to	Superior conj.	36 days	220 days
Superior conj.	to	Elongation East	36 days	220 days
Elongation East	to	Inferior conj.	22 days	72 days

The greatest brilliancy of Venus always occurs about a month *before* greatest western elongation (as a morning star), or a month *after* greatest eastern elongation (as an evening star). No such rule can be given for Mercury, because its distance from Sun and Earth can vary over a wide range.

Mercury is not likely to be seen unless a clear horizon is available; it is seldom seen as much as 10 degrees above the horizon in the twilight sky. In general it may be said that the most favourable times for seeing Mercury as an evening star will be in spring, some days before greatest eastern elongation; in autumn it may be seen as a morning star some days after greatest western elongation.

Venus is the brightest of the planets, and may be seen on occasions in broad daylight. Like Mercury, it is alternately a morning and an evening star, and will be highest in the sky when it is a morning star in autumn, or an evening star in spring. Venus is seen to best advantage when it comes to greatest eastern elongation in June; it is then well north of the Sun in the spring months and is a brilliant object in the sunset sky over a long period.

The superior planets, which travel in orbits larger than that of the Earth, differ from Mercury and Venus in that they can be seen opposite the Sun in the sky. The superior planets are morning stars after conjunction with the Sun, rising earlier each day until they

come to opposition. They will then be in the south at midnight, and visible all night. After opposition, they are evening stars, setting earlier each evening until they set in the west with the Sun at the next conjunction. The interval between conjunctions or between oppositions is greatest for Mars (over two years). At the time of opposition, the planet is nearest the Earth, and therefore at its brightest. This change in brightness is most noticeable with Mars, whose distance from the Earth can vary considerably; the other superior planets are at such great distances that there is very little change in brightness from one opposition to another. The effect of altitude is, however, of importance, for at a December opposition the planet will be among the stars of Taurus or Gemini, and can then be at an altitude of more than 60 degrees in southern England. At a summer opposition, when the planet is in Sagittarius, it may only rise to about 15 degrees above the southern horizon, and so make a less impressive appearance.

Mars, which travels in a very eccentric orbit, comes nearest to the Earth at an opposition at the end of August; it may then be brighter even than Jupiter, but rather low in the sky in Aquarius. These favourable oppositions occur every fifteen or seventeen years (1924, 1941, 1956, 1973), but in this country the planet is probably better seen at an opposition in the autumn or winter, when it is higher in the sky. Oppositions of Mars occur at an average interval of 780 days, and during this time the planet makes a complete circuit of the sky.

Jupiter is always a bright planet, and comes to opposition a month later each year, having moved, roughly speaking, from one zodiacal constellation to the next.

Saturn moves much more slowly than Jupiter, and may remain in the same constellation for several years. The brightness of Saturn depends on the aspect of its rings, as well as on the distance from Earth and Sun. At present the rings are well open, so that the planet is quite a bright object.

Uranus, *Neptune* and *Pluto* are hardly likely to attract the attention of observers without adequate instruments, but some notes on their present positions in the sky will be found in the February and May notes.

The Planets in 1962

Mercury moves so quickly among the stars that it is not possible to indicate its position on the star charts at a convenient interval. The monthly notes must be consulted for the best times at which this planet may be seen.

The positions of the other planets are given in the table on the opposite page. This gives the apparent longitudes on dates which correspond to those of the star charts, and the position of the planet may at once be found near the ecliptic at the given longitude.

Examples:

(1) *What is the bright planet seen below Castor and Pollux at 3 a.m. (Summer Time) on September 20?*
The time is 2^h G.M.T., and from the table on p. 2, chart 11 is found to be appropriate. The longitude of the planet is at once seen to be about 110 degrees to 120 degrees, and from the table opposite, it is identified as Mars.

(2) *Where can Mars be found on October 25?*
This is before opposition, so Mars is a morning star, and from the table opposite, its longitude is found to be 125 degrees. Using, say, chart 12L, it is seen that Mars is then in Cancer, to the east of Gemini, and will be well seen on October 25 at 2^h; other convenient times may be found from adjacent charts.

Phases of the Moon, 1962

New Moon				*First Quarter*				*Full Moon*				*Last Quarter*			
Jan.	6^d	12^h	35^m	Jan.	13^d	5^h	01^m	Jan.	20^d	18^h	16^m	Jan.	28^d	23^h	36^m
Feb.	5	0	10	Feb.	11	15	43	Feb.	19	13	18	Feb.	27	15	50
Mar.	6	10	31	Mar.	13	4	39	Mar.	21	7	55	Mar.	29	4	11
Apr.	4	19	45	Apr.	11	19	50	Apr.	20	0	33	Apr.	27	12	59
May	4	4	25	May	11	12	44	May	19	14	32	May	26	19	05
June	2	13	27	June	10	6	21	June	18	2	02	June	24	23	42
July	1	23	52	July	9	23	39	July	17	11	41	July	24	4	18
July	31	12	24	Aug.	8	15	55	Aug.	15	20	09	Aug.	22	10	26
Aug.	30	3	09	Sept.	7	6	44	Sept.	14	4	11	Sept.	20	19	36
Sept.	28	19	39	Oct.	6	19	54	Oct.	13	12	33	Oct.	20	8	47
Oct.	28	13	05	Nov.	5	7	15	Nov.	11	22	03	Nov.	19	2	09
Nov.	27	6	29	Dec.	4	16	48	Dec.	11	9	27	Dec.	18	22	42
Dec.	26	22	59												

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GEOCENTRIC LONGITUDES OF THE PLANETS, 1962

DATE		*Venus*	*Mars*	*Jupiter*	*Saturn*	*Uranus*	*Neptune*
January	6	280°	279°	312°	300°	151°	223°
	21	299°	291°	315°	302°	150°	224°
February	6	319°	303°	319°	304°	149°	224°
	21	338°	315°	323°	306°	149°	224°
March	6	355°	325°	326°	307°	148°	224°
	21	13°	337°	329°	309°	148°	224°
April	6	33°	350°	333°	310°	147°	223°
	21	51°	1°	336°	311°	147°	223°
May	6	69°	13°	338°	311°	147°	223°
	21	87°	24°	340°	312°	147°	222°
June	6	107°	36°	342°	311°	147°	222°
	21	125°	47°	343°	311°	148°	222°
July	6	143°	58°	343°	310°	148°	221°
	21	160°	68°	343°	309°	149°	221°
August	6	177°	79°	341°	308°	150°	221°
	21	193°	89°	340°	307°	151°	222°
September	6	208°	99°	338°	306°	152°	222°
	21	221°	108°	336°	305°	153°	222°
October	6	231°	117°	334°	305°	154°	223°
	21	236°	125°	333°	305°	154°	223°
November	6	232°	133°	333°	306°	155°	224°
	21	225°	139°	334°	307°	155°	224°
December	6	223°	143°	336°	308°	156°	225°
	21	229°	146°	338°	309°	156°	225°
Conjunction:							
Superior		Jan. 27	—	Feb. 8	Jan. 22	Aug. 24	Nov. 6
Inferior		Nov. 12	—	—	—	—	—
Opposition:		—	(1963)	Aug. 31	July 31	Feb. 17	May 5

Monthly Notes, 1962

January

New Moon: January 6 *Full Moon:* January 20

EARTH is at perihelion (nearest to the Sun) on January 2; its distance from the Sun at this time will be 91,400,000 miles.

MERCURY is at greatest eastern elongation (19 degrees) on January 21, and is then theoretically an evening star. It will, however, be very low in the south-west at twilight, but may reach 5 degrees altitude at that time in southern England.

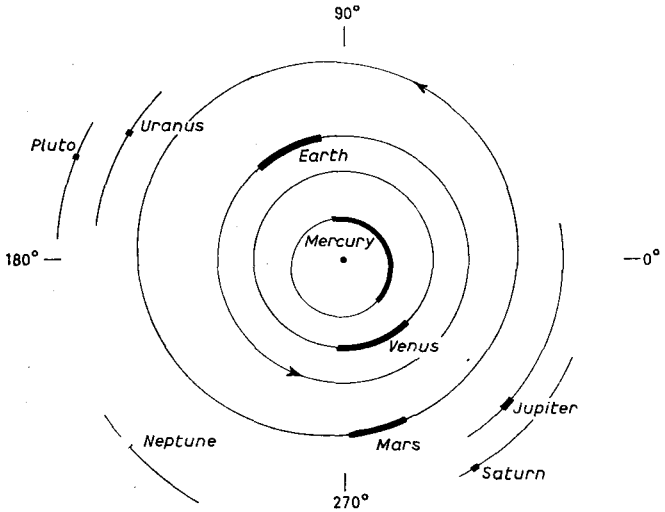
VENUS comes to superior conjunction with the Sun on January 27, and will not be visible this month. After conjunction, the planet moves slowly out from the Sun and will be seen as an evening star until November.

MARS was in conjunction with the Sun on December 14, 1961, and will be a morning star throughout 1962. The planet is now on the far side of its orbit (see diagram below), and the Earth overtakes it very slowly. For the first few months of the year, Mars remains well south of the Sun, and although its elongation increases, it rises at dawn during this period. It is not likely to be seen in the eastern sky before dawn until the end of May.

JUPITER is still an evening star, but is approaching conjunction. At the beginning of January it may be glimpsed, low in the south-west after sunset; by the end of the month it will set only half an hour after the Sun.

SATURN is in conjunction with the Sun on January 22, and will not be visible this month. The planet is far south of the equator and is not well placed for observation in this country; it will not begin to be seen as a morning star until March.

The illusion of size. Constellations such as Orion and Gemini seem to be enormous as we look up at them in the sky. This is a typical illusion; we are accustomed to judging the sizes of things by earthly standards, and when we look up in this way, with nothing



Planetary Orbits in January

to act as a standard of comparison, our judgment seems to be affected. The Full Moon sometimes appears to be as big as a plate, but measurement shows that it has not altered – and one can still cover it with the tip of a little finger at arm's length. In the same same way, Orion, which appears so huge, can be covered with an ordinary postcard in an outstretched hand. This is an easy way to remember the shape of Orion; a postcard, with a star at each corner for his shoulders and feet, and three stars across the middle for his belt. Above his shoulders are three little stars which mark his head. Few people would believe that the Full Moon could be fitted inside this triangle without difficulty. This can only be proved by calculation, since the Moon does not pass through the triangle, but it may be possible to make a comparison when the Moon passes north of Orion each month – for instance, on the nights of January 17, or February 13 – or, best of all, on the night of the December Full Moon, December 11.

Cor Caroli. On a January evening at about 22^h, Leo the Lion and Ursa Major, the Great Bear, are well displayed in the eastern sky. A line from *Denebola* (the tail of the Lion) to *Benetnasch* (the last

star in the tail of the Bear, or the handle of the Plough) may be seen to be divided into three roughly equal parts by the star cluster of Coma Berenices and the star *Cor Caroli.* This is a fine double star, the brightest in the constellation Canes Venatici, the Hunting Dogs, and its name (Charles' Heart) is in remembrance of King Charles II. The story goes that on the evening before the return of Charles to London, the court physician, Scarborough, remarked that this star shone with a peculiar lustre, and suggested that it should be named in honour of the King. It is certainly true that many old star atlases (even those of a much later date) marked the star with a picture of a heart surmounted with a crown. The star actually had its place on the collar of Chara, one of the hunting dogs, but the incongruity of the crowned heart did not seem to matter! In later atlases and globes, the royal heart disappeared, but it is perhaps fitting that the king who founded the Royal Society and the Royal Observatory should be remembered in this simple way.

Coma Berenices. The star cluster of Coma Berenices represents the tress of hair which Queen Berenice had dedicated to the gods, but which was stolen from the temple. According to the court astrologer, Conon, the gods had accepted the sacrifice, and translated it to the sky for all men to admire. The cluster is certainly a fine object, and is well worth studying with a pair of binoculars. The real interest of Coma is only revealed by large telescopes. In this constellation lies the north pole of the Galaxy, and here, at 90 degrees from the plane of the Milky Way, are crowded innumerable faint nebulæ, all of them far beyond the boundaries of our own Galaxy. These extra-galactic nebulæ are found in great clusters; on one photographic plate, covering less than two degrees each way, about 800 of them have been found. In this part of the sky, the spiral and elliptical nebulæ outnumber the stars. The Coma cluster of nebulæ lies closer to us than the cluster in Corona Borealis (see April Notes), the distance being about 130 million light years. In the neighbouring constellation of Virgo, there is an even larger association of nebulæ, but these are closer still, and appear to cover a larger area of the sky.

February

New Moon: February 5 *Full Moon:* February 19

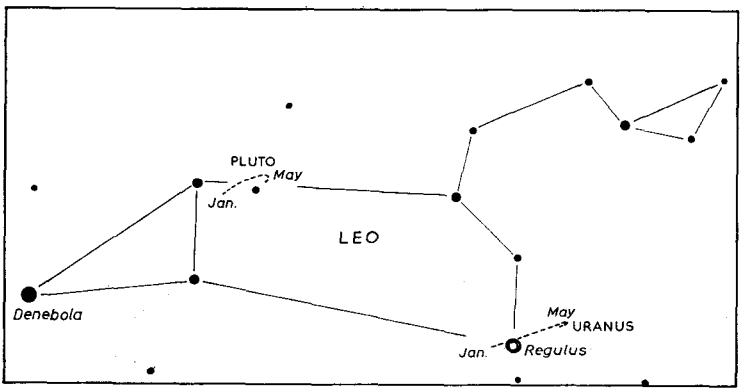
MERCURY is at inferior conjunction on February 5, and will not be seen during the month in these latitudes.

VENUS now begins to appear as an evening star, low in the south-west at sunset. Its elongation from the Sun increases only very slowly, but it may be possible to see the planet at the end of the month, when it sets half an hour after the Sun.

MARS moves through Capricornus during the month, overtaking Saturn on February 6. The planets are, however, too near the Sun to be seen without adequate instruments.

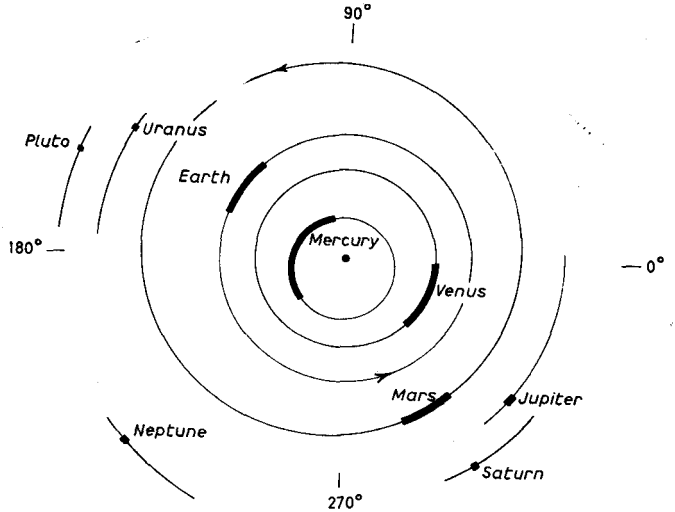
JUPITER is in conjunction with the Sun on February 8, and will not be visible.

SATURN is moving direct in Capricornus, but is still too close to the Sun to be seen in the morning sky.



URANUS is at opposition this month, and will be found close to the bright star *Regulus* in Leo. The characteristic loop in the path

of the planet takes place in the neighbourhood of *Regulus* (see diagram above), so that Uranus actually passes this star three times. On the first occasion, on October 11, 1961, the planet was moving direct, but this time, on February 1, 1962, the motion is retrograde, and Uranus passes about a third of degree north of *Regulus*; the third conjunction of the planet and the star takes place on July 27, 1962. Uranus at this opposition (February 17) will be about 1,613 million miles from the Earth. Its magnitude is 5·7, so that it is just possible to see it with the naked eye. In a small telescope it is seen as a greenish disk.



Planetary orbits in February

PLUTO is also at opposition this month, and although not visible to the naked eye, or even in a small telescope, it is interesting to note its position in relation to Uranus. Pluto will be rather more than 3,000 million miles from the Earth at its opposition on February 27; the diagram shows only the retrograde portion of its apparent path among the stars.

A total eclipse of the Sun will occur on February 4–5, but the path of totality lies wholly in the Pacific Ocean. *A penumbral eclipse of the Moon* on February 19 occurs at midday, and will also be invisible from this country.

An occultation of the bright star *Aldebaran* takes place on February 12. The Moon will then be at First Quarter, and the star will disappear at the dark limb shortly before 23^h. The occultation is almost central, and *Aldebaran* will not reappear at the bright limb until a few minutes before midnight.

The brightest stars. The brilliance of the stars in our winter skies is no illusion, but is a very real effect. At this season more than a dozen of the brightest stars in the sky are visible at one time. Thus at midnight in February, we see Orion in the south-west, its two brightest stars, *Betelgeuse* and *Rigel*, presenting a remarkable contrast. *Betelgeuse* is one of the largest stars, a variable red giant, while *Rigel* is one of the most luminous stars known. To the left of Orion is *Sirius*, the brightest star in the sky, and one of the nearest. A line from *Sirius* through Orion's belt reaches *Aldebaran*, another red star, but at only a tenth of the distance of *Betelgeuse*.

Above *Sirius* is *Procyon*, the two forming a great equilateral triangle with *Betelgeuse*, and still higher in the sky are the Twins, *Castor*, the remarkable sextuple star, and *Pollux*. Still farther to the east are to be seen *Regulus*, in Leo, and *Spica* in Virgo; while *Arcturus* rises in the east and *Vega* and *Deneb* skirt the northern horizon. *Capella*, to be found above Orion in the west, is a circumpolar star at all latitudes in these islands.

March

New Moon: March 6 *Full Moon:* March 21

EQUINOX: March 21.

MERCURY is at greatest elongation west of the Sun (27 degrees) on March 3, but although it is then a morning star, it is well south of the Sun and is not likely to attain 5 degrees altitude in the dawn sky in this country.

VENUS is now moving steadily out from the Sun, and may be seen in the western sky at sunset. At the end of March it sets more than an hour after the Sun.

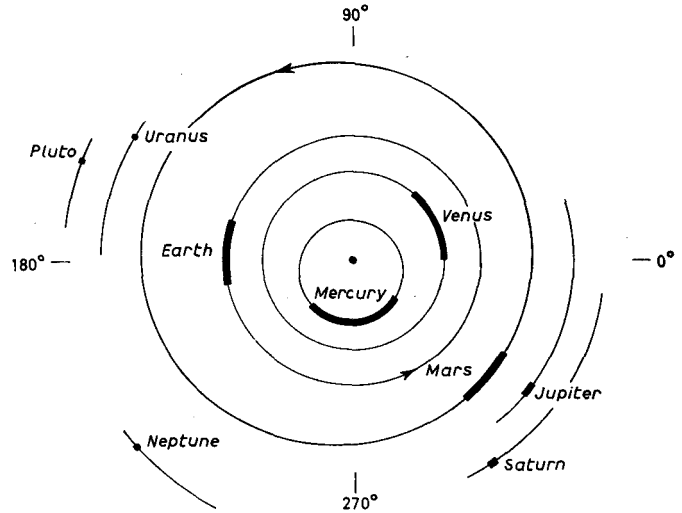
MARS still rises with the dawn and its apparent path takes it very close to Jupiter on March 6. Unfortunately, the two planets will then be only 20 degrees from the Sun, and will not be visible to the naked eye in the bright sky before sunrise.

JUPITER now begins to move out from the Sun, but even at the end of the month it rises only a few minutes before dawn.

SATURN is a morning star, rising before dawn in the south-east. By the end of the month it rises nearly two hours before the Sun, and may be seen in the centre of the constellation Capricornus. The magnitude of the planet is +0·9.

The Equinox, where the Sun crosses the equator on its way north, is the point from which our astronomical measurements of right ascension or longitude are made. It is often called the 'spring' equinox, although this term is really only applicable in the northern hemisphere. There is, of course, a similar equinox (the 'autumn' equinox) at longitude 180 degrees, exactly opposite; the Sun passes through this point at the end of September.

The position of the 'spring' equinox in the sky may be found below and almost in a line with the stars Alpha Andromedæ and Gamma Pegasi, which form the left-hand side of the Great Square of Pegasus. The exact position is continuously changing because of precession, the equinox moving westwards about one degree in seventy years; and it is determined by measurements of the



Planetary orbits in March

position of the Sun, or from photographs of the positions of certain minor planets.

The spring equinox is still called the First Point of Aries because in Greek times it did fall in the constellation of Aries. It is now 30 degrees away in the constellation Pisces, and before long it will pass into Aquarius.

The largest constellation. This is a convenient time of year at which to trace the windings of the long constellation of Hydra, the Water Snake. Stretching over about 100 degrees – more than a quarter of the sky – it is marked mainly by faint stars, and its only conspicuous object is the reddish star *Alphard* (the Solitary One). Although only of the second magnitude, *Alphard* looks much brighter because of its isolated position. It is easily found below the Sickle of Leo, and it forms a huge triangle with the stars *Regulus* and *Procyon*. These again form a large equilateral triangle with *Sirius*, so that the group of five stars – *Regulus*, *Alphard*, *Procyon*, *Sirius* and *Betelgeux* – forms a great sprawling letter W in the south-western sky in mid-evening.

In area, Hydra is the largest of the constellations. These areas are not difficult to calculate nowadays, because the boundaries of all the constellations are straight lines, or, to be more precise, arcs of great circles on the celestial sphere. Before 1930 the boundaries were left to the fancy of the artists who designed the old pictorial star atlases, and there was little general agreement as to how the boundaries should be drawn to include the outstretched arm of a figure, or the tail of an animal. In 1930, under the direction of Eugene Delporte of the Brussels Observatory, the boundaries were fixed as regular lines, and now it is definitely possible to assign any particular star to one constellation only. Of the eighty-eight constellations, Hydra is the largest, followed by Virgo, Ursa Major and Cetus; the smallest are Sagitta and Equuleus, in the northern hemisphere, and Crux, near the South Pole.

The Northern Crown. In late evening in March the constellation of Boötes (the Herdsman) is well up above the eastern horizon. It is easily recognized because its stars form a great letter P lying on its back, the golden star *Arcturus* being at the foot of the letter. This fine star may also be found by following the curve of the handle of the Plough (or the tail of the Great Bear), but the Plough is somewhat difficult to find at this season, as it is high in the sky, almost overhead – the last place where one expects to find it.

Below Boötes is the little circlet of stars known as Corona Borealis, the Northern Crown. This has always been a favourite group with star gazers, and its stars have more pet names and classical allusions than most other constellations. Its brightest star, *Alphecca*, is also known as *Gemma* and *Margarita Coronæ*.

Here in Corona, well away from the dust and gas clouds of the Milky Way, the astronomer can gaze out into the great distances of space. There are some remarkable groups of nebulæ in this part of the sky, and in one such cluster in Corona, more than 400 nebulæ are to be found in an area that could be covered by the Full Moon. This cluster is probably at a distance of about 400 million light-years.

April

New Moon: April 4 *Full Moon:* April 20

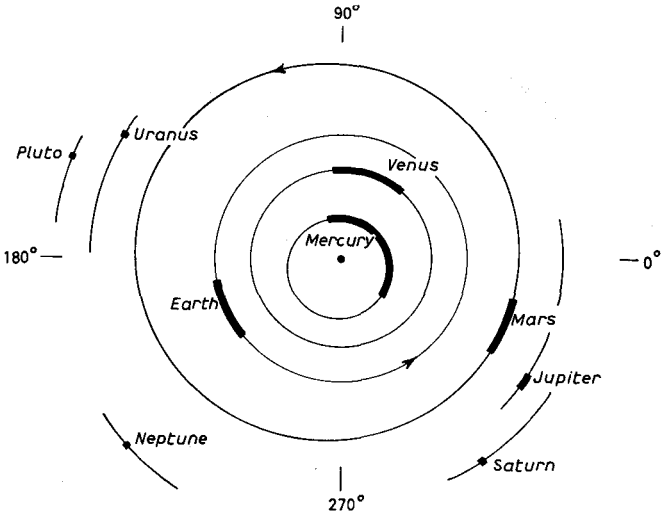
MERCURY is at superior conjunction on April 16, and will not be seen during the month.

VENUS is an evening star, setting in the west about two hours after the Sun. It has now moved well north of the Sun, and is displayed to better advantage in the evening sky. Its magnitude is now −3·3, but it will be a whole magnitude brighter than this in the autumn.

MARS still appears to be keeping pace with the Sun, and rises at dawn. During the month it passes into the constellation Pisces, and comes north of the equator on April 22. The planet is at perihelion on April 13, its distance from the Sun being 128 million miles.

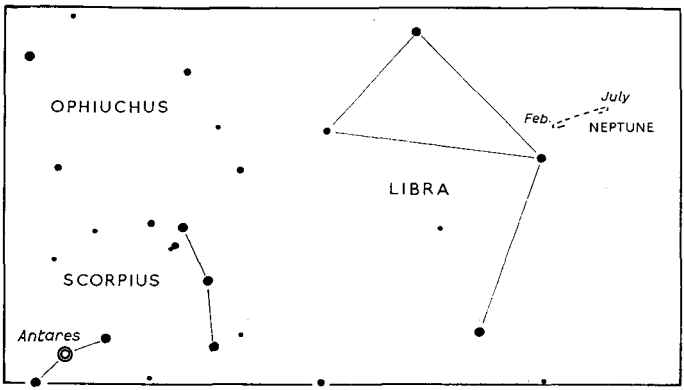
JUPITER now begins to rise before dawn, and may easily be recognized because of its brilliance – it is the brightest of all the objects in the morning sky. Its magnitude is −1·6, and it is moving direct in the constellation Aquarius.

SATURN is also a morning star, and may be seen before dawn about 20 degrees west of the more brilliant Jupiter. The magnitude of Saturn is +0·9, so that Jupiter is two and a half magnitudes brighter, or ten times as bright. Saturn is, however, much brighter than any of the stars in the neighbourhood.



Planetary orbits in April

An occultation of the star *Regulus* in Leo takes place on April 14. The Moon, ten days old, will move to the left (east), its dark limb obscuring the star at about $23^h\ 16^m$. *Regulus* will remain occulted for more than an hour, reappearing at the bright limb at about half an hour after midnight.



Path of Neptune. A description is given on page 23.

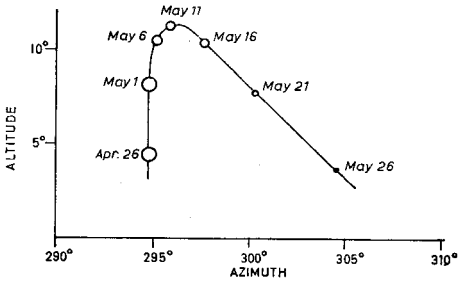
The Zodiacal Light. The Zodiacal Light is a broad faint patch of light that can be seen after sunset or before sunrise, stretching up from the horizon from the Sun's place of setting or rising. The light is wedge-shaped, brightest at its base, and tapers off along the ecliptic. It is best seen in these latitudes on spring evenings in the western sky after sunset, or on autumn mornings in the east before sunrise. It is not easy to see, although one is likely to see it more frequently than, say, an eclipse of the Sun, or even an appearance of the planet Mercury. But to see it at its best, one must go to the tropics, where the ecliptic rises steeply from the horizon, and where, in perfect conditions, the band of light can be seen to extend right round the sky.

The Zodiacal Light is caused by the reflection of sunlight from interplanetary dust, which surrounds the Sun and extends at least as far as the Earth, and perhaps even to the orbit of Jupiter. It has long been considered to be an extension of the solar corona, but both objects are faint and difficult to photograph because of the scattering of light from dust in the Earth's atmosphere. Ten years ago our knowledge of this subject was very limited; the corona could be traced a short way out from the Sun at a total eclipse, and the Zodiacal Light could be measured in the twilight sky for some distance in towards the Sun, but there was a large gap in the measurements. This gap has now been closed, largely as the result of the work of Dr D. E. Blackwell, formerly working at the Cambridge Observatories, and now Professor of Astronomy at Oxford. Photographs taken from an open aircraft at 30,000 feet during the total eclipse of June 1954 extended our knowledge of the corona to a distance of 14 degrees from the Sun. An expedition to the Andes in 1958 (to Chacaltaya in Bolivia, at a height of 17,000 feet) gave still further valuable results, and it is now certain that the Zodiacal Light and the corona are closely related; it has also been shown that the Zodiacal Light is definitely variable, increasing in brightness after outbursts of solar activity. A joint Oxford-Cambridge expedition was sent to Bolivia to continue this work in 1961.

May

New Moon: May 4 *Full Moon:* May 19

MERCURY is at greatest elongation east (22 degrees) on May 13, when it will be some degrees north of the Sun and favourably placed as an evening star. It is brighter before the actual date of elongation, but this is not always the deciding factor in spotting this elusive planet. The diagram shows the changes in altitude and azimuth (true bearing from north through east, south and west) of Mercury at the time when the Sun is 6 degrees below the horizon – approximately three-quarters of an hour after sunset at this season of the year. The altitudes are always small, but with good visibility and a clear horizon to the north of west it should be possible to find the planet.



Mercury

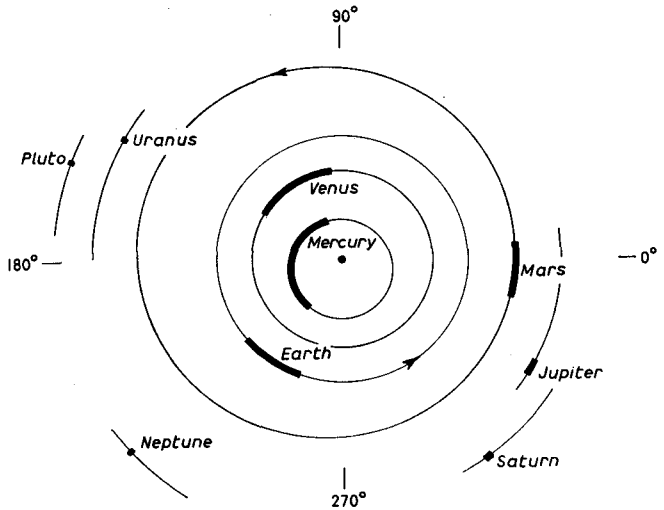
VENUS remains an evening star, and during the month reaches its most northerly declination (25 degrees) during the year; at the end of May it sets more than two hours after the Sun. Venus will be seen about 6 degrees north of the bright star *Aldebaran* on the evening of May 6.

MARS now begins to move out from the Sun more rapidly as it comes into northern declinations. By the end of the month it should be possible to find the planet in the east just before dawn. It is in the constellation Aries, just below *Hamal* (Alpha Arietis);

Mars is the brighter (magnitude +1·4) and may be distinguished by its red colour, which is very noticeable in binoculars.

JUPITER is a morning star, rising an hour before dawn at the beginning of the month. The planet is very bright (magnitude −1·8) and will be found close to the small star Lambda Aquarii (magnitude +3·8); the planet is moving slowly to the east, and will pass about half a degree south of the star on May 28.

SATURN is also a morning star, moving slowly towards a stationary point in Capricornus, which is reached on May 22. The planet, now a little brighter (magnitude +0·8), rises at midnight at the end of May.



Planetary orbits in May

NEPTUNE comes to opposition on May 3 (see diagram on page 20), when its distance from the Earth is 2,730 million miles. The planet is invisible to the naked eye, but with suitable optical means it will be found near the star Alpha Libræ (*Zuben el*

Genubi). The magnitude of Neptune is only 7·7; and in binoculars or a small telescope, it is unlikely to be distinguished from other faint stars. Its slow retrograde motion will serve to mark it as a moving planet, but this calls for patient observation over many nights.

Libra. The constellation of Libra, in which Neptune is moving at present, formed at one time the right-hand part of Scorpius, and was known as the 'Claws of the Scorpion'. In the first century B.C. it became known as Libra, the Scales or Balance, presumably because at that time the Sun was in this part of the sky at the autumn equinox, when day and night are equal. The equality thus suggested the idea of the scales, although they are not exactly balanced, as drawn in the old star atlases.

The three main stars of Libra form a triangle with the point upwards. The Arabic names of two of these stars remind us of the original constellation. The right-hand star of the triangle, Alpha Librae, bears the name *Zuben el Genubi*, meaning the Southern Claw. Because it lies almost exactly on the ecliptic, it was used in ancient times as one of the marks of progress of the Moon and planets round the sky. Today it is one of the fifty-seven navigational stars. *Zuben el Genubi* is a double star, but although the two stars are widely separated, they are of unequal brightness, and require a pair of field-glasses to distinguish them. Beta Librae, at the top of the triangle, has the Arabic name *Zuben el Chamali* (the Northern Claw), but the third star, Gamma Librae, at the left of the triangle, does not appear to have an ancient name of this kind, in spite of statements to the contrary in many books.

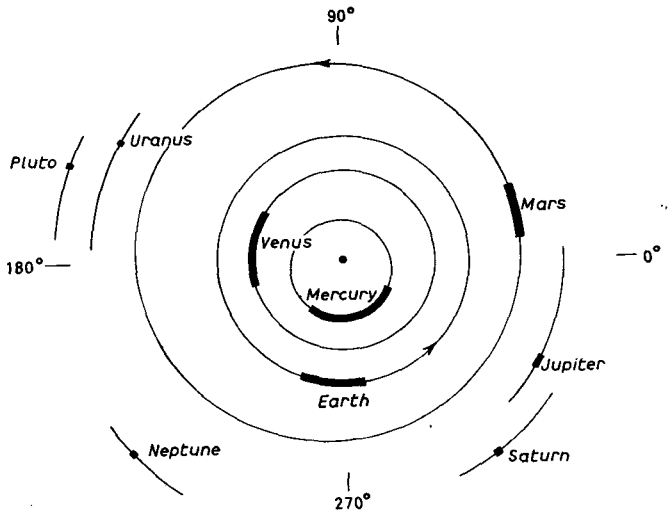
June

New Moon: June 2 *Full Moon:* June 18

SOLSTICE: June 21.

MERCURY will not be visible this month. It comes to inferior conjunction on June 7, and although moving out to greatest western elongation at the end of the month, it is south of the Sun and badly placed for observation in the bright dawn sky.

VENUS remains a brilliant evening star in the western sky for more than two hours after sunset. It is now beginning to move south again, and its period of visibility becomes less each evening. Venus will pass a few degrees south of the Twins, *Castor* and *Pollux*, on June 11.



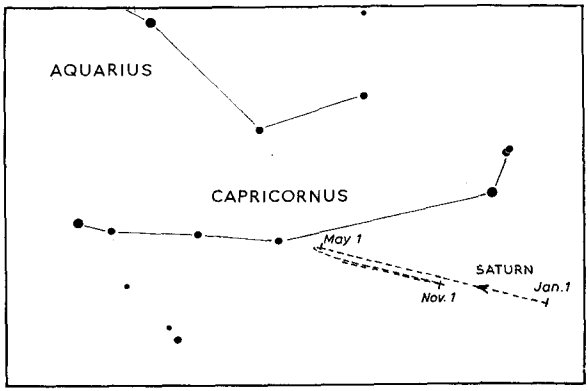
Planetary orbits in June

MARS now begins to be visible as a morning star, rising nearly an hour before the Sun at the beginning of the month. It is now

passing through Aries, and will rise north of east; at the end of June it passes into Taurus, and will be seen to the right of the Pleiades.

JUPITER is now well seen in the morning sky; it rises before midnight at the end of the month. The planet is in Aquarius, moving slowly eastwards from the star Lambda, and by the end of the month its brightness will have increased appreciably to magnitude −2·1.

SATURN is now moving retrograde and growing brighter as it approaches opposition. It rises before midnight and will be seen in the south at dawn. The diagram below shows the apparent path of Saturn among the stars of Capricornus.



Saturn

No night in June. The Sun reaches its highest point in the sky in our latitudes at the solstice on June 21, when it will be 23½ degrees north of the equator. It then rises at its maximum bearing north of east, and sets north of west, taking more than twelve hours for its passage across the sky, so that we have long days and short nights at this time of year. From the astronomer's point of view, there is no night at all in these latitudes, for by definition twilight does not

end until the Sun is 18 degrees below the horizon. In the summer months in this country, however, the Sun cannot sink to such an angle, even below the northern horizon, so that it never becomes completely dark. Thus in London at the solstice, the Sun is only 15 degrees below the northern horizon at midnight, while in Aberdeen the depression at midnight is only about 9 degrees. The following table shows the dates between which there is no true night at different latitudes:

Lat.
51° (Southern England) from May 26 to July 18
53° (Midlands) from May 16 to July 28
55° (Northern England) from May 8 to August 5
57° (Scotland) from May 1 to August 12

Still further north, in latitudes greater than 66½ degrees, there will always be at least one day in the year when the Sun does not set, but merely circles the sky during the whole twenty-four hours. This is the so-called 'midnight sun', and a glance at the atlas will show that there are many countries which might claim to be the 'Land of the Midnight Sun' in the northern hemisphere. In southern latitudes, the midnight Sun will be visible only from Antarctica.

July

New Moon: July 1 and 31 *Full Moon:* July 17

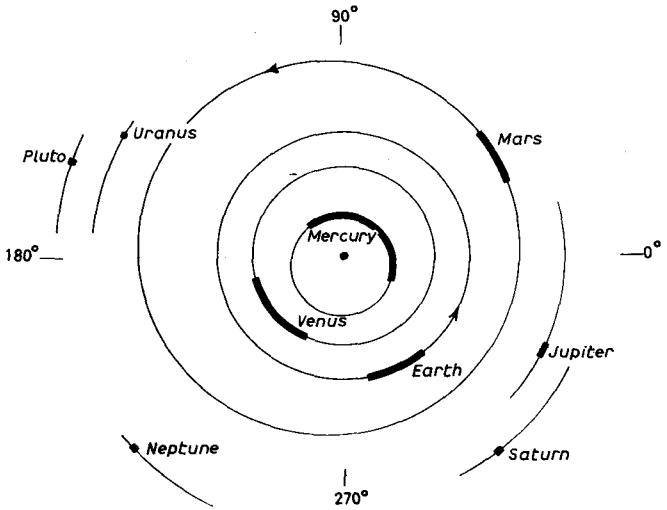
EARTH is at aphelion (farthest from the Sun) on July 4, when the distance will be 94,500,000 miles.

MERCURY comes to greatest elongation west (22 degrees) on July 1, but will then be well south of the Sun, and is unlikely to reach 5 degrees altitude in the east in the dawn twilight. Superior conjunction takes place on July 29.

VENUS is still a brillliant evening star at sunset, but now sets rather less than two hours after the Sun. Venus will pass about a degree north of the planet Uranus on July 11, but the actual conjunction occurs in the early morning, and by midnight the planet will have moved east to be north of *Regulus*. In the late evening of July 11, this configuration of two planets and a bright star should be well worth observing with binoculars or a small telescope with a wide field of view.

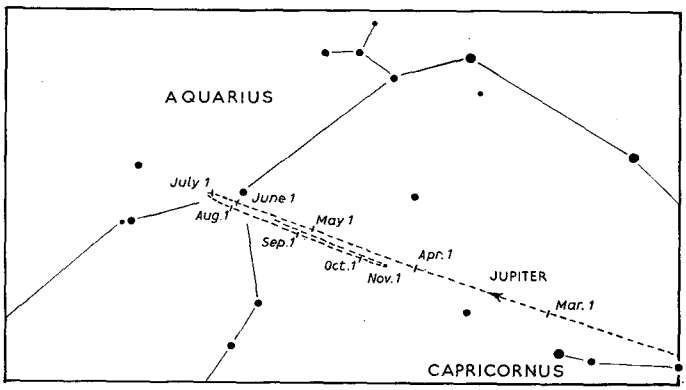
MARS is a morning star, rising nearly two hours before dawn. The planet is still moving north (while the Sun is moving south) and conditions are therefore more favourable. Mars passes between the star clusters Pleiades and Hyades during the month, and will be seen about 5 degrees north of *Aldebaran* on July 23. Both star and planet are of a reddish colour, but *Aldebaran* is brighter than Mars at present.

JUPITER rises before midnight, and will be seen in Aquarius, under the right-hand side of the Great Square of Pegasus. The planet reaches a stationary point on July 3, after which its apparent motion becomes retrograde, so that it moves back again towards the star Lambda Aquarii. The diagram shows the apparent path of Jupiter from March to the end of the year.



Planetary orbits in July

SATURN now rises in mid-evening, and comes to opposition on July 31, when it will be at its brightest (magnitude +0·4) and nearest to the Earth at a distance 831 million miles.



Jupiter

A penumbral eclipse of the Moon occurs at midday on July 17, but will not be visible from this country. **An annular eclipse of the Sun** on July 31 will be seen only from the Atlantic Ocean and Africa.

Ophiuchus. In southern latitudes the constellations of Scorpius and Sagittarius are the most brilliant in the sky, but in this country we see only the northern parts of these star-groups, and their brilliance is dimmed owing to their low altitude. But it is interesting to notice that between these two great Zodiacal figures another intrudes, cutting right across the broad band of the Zodiac into southern skies. This is Ophiuchus the Serpent Bearer, a giant figure holding a great snake in his hands. The Snake forms a separate constellation, Serpens, which is divided into two parts, Serpens Caput, the Head, and Serpens Cauda, the Tail, one to the right and the other to the left of Ophiuchus, but both north of the ecliptic. Ophiuchus himself penetrates right over the ecliptic as far as 30 degrees south of the equator. The result is that the Sun, Moon and planets, moving along the ecliptic, pass through a mere strip of the north end of Scorpius, but then must pass through the whole width of Ophiuchus before reaching Sagittarius. And yet Ophiuchus is never quoted as being one of the Zodiacal constellations! If we allow for the wanderings of the planets for some degrees north or south of the ecliptic, we find that they may actually pass through the corners of other constellations – the northern parts of Cetus, of Sextans, and of Orion. But they all have to pass through Ophiuchus!

August

Full Moon: August 15 *New Moon:* August 30

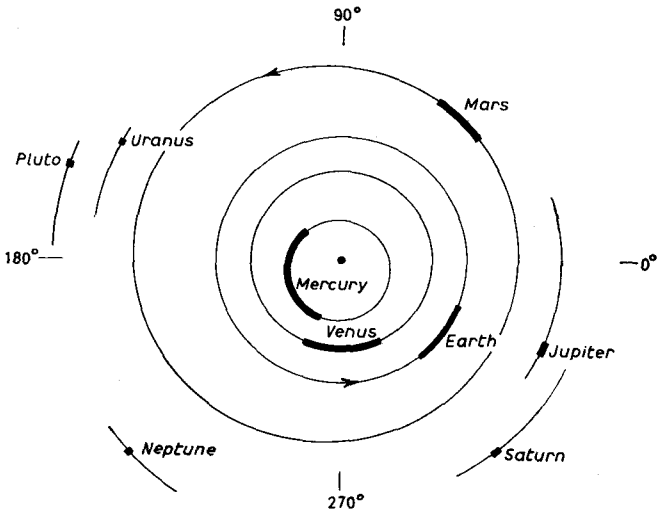
MERCURY was at superior conjunction at the end of July, and will not be visible.

VENUS sets earlier each evening and is now visible for only about an hour after sunset. The planet passes close to *Spica* on the night of August 30, but will set before the time of closest approach.

MARS continues its rapid motion to the east, and passes from Taurus into Gemini, reaching its highest northern declination (+24 degrees) at the end of the month. Mars now rises at midnight, and is nearly as bright as *Pollux*, some degrees to the east.

JUPITER continues its retrograde motion, and passes Lambda Aquarii again on August 7, this time about 1 degree south of it. Jupiter is at opposition on August 31, a brilliant object, magnitude −2·4, below the right-hand side of the Great Square of Pegasus. The distance of the planet at opposition is 370 million miles.

SATURN has passed opposition, and is now an evening star, still



Planetary orbits in August

moving slowly retrograde in Capricornus; the planet fades to magnitude +0·6 by the end of the month. The rings of Saturn, which are visible in a small telescope, are now closing again. They are tilted at an angle of only 17 degrees as compared with the 27 degrees in 1958. The north side of the rings is tilted towards us, but the broad rings no longer hide the south pole of the planet, which now appears below the nearer edge of the outer ring.

A penumbral eclipse of the Moon occurs on August 15, lasting from $18^h\ 16^m$ to $21^h\ 39^m$. The Moon rises in this country at about $19^h\ 30^m$, but to the naked eye will not appear to be any different from usual, although it must suffer some diminution of light as it passes through the penumbra of the Earth's shadow.

Fomalhaut. The bright star which can be seen low in the sky to the south of Jupiter is *Fomalhaut*, the brightest star of the constellation Piscis Austrinus, the Southern Fish. In the old star atlases it represented the mouth of the Fish, into which Aquarius is pouring the water from his jar. *Fomalhaut* is one of the 'Royal Stars' that were used in ancient times to mark the four quarters of the sky, and hence the seasons. The other three – *Aldebaran*, *Regulus* and *Antares* – are all close to the ecliptic and, in fact, each in turn may be occulted by the Moon at different times. *Fomalhaut*, however, is far south of the ecliptic, and its selection as a Royal Star was obviously dictated by the fact that there is no other bright star in this part of the sky that would serve.

Jupiter passed north of *Fomalhaut* in July, but was then a morning star, in the south at about 3^h. Fomalhaut is 30 degrees south of the equator, so that it never rises to an altitude of more than 9 degrees in southern England. When it is seen in this way, low in the south, it is overhead in South Africa.

The Sun's position in space. High overhead on an August evening is the bright star *Vega*, towards which the Sun is moving at about 12 miles a second. This figure is measured with reference to the brighter stars, all of which are moving through space in the same way. It was Edmond Halley who pointed out in 1718 that the star *Arcturus* had moved through more than a degree since its position

was first described by Ptolemy about 1,600 years previously. Accurate star positions did not become available until many years later, and it was not until the end of the eighteenth century that William Herschel made the first analysis of the movements of such stars as *Sirius*, *Arcturus* and *Procyon*. From the movements of thirteen such stars, Herschel was able to show that these stars appear to open out in front of the advancing Sun, and close in behind it, and he calculated the speed and direction of motion of the Sun. Modern investigations, using far more stars, have hardly altered Herschel's values.

Herschel was of the opinion that there is not one fixed star in the heavens. This is, of course, quite true, and today we have catalogues giving the annual change in positions of many thousands of stars. Generally speaking the largest values of these changes, which are called proper motions, are given by the nearer stars, and the measurement of a large proper motion is often the only means of detecting a nearby star, which may be quite a faint object. Only about fifty stars are known to move as fast, or faster than *Arcturus*. It will be realized that the proper motion of a star is really caused by a combination of the movement of the star with that of the Sun through space. The actual motion of the star is only known when the effect of the solar motion is removed.

Which way is the Earth moving? In addition to sharing the motion of the Sun through space, the Earth also has its own motion of annual revolution about the Sun. Since the orbit of the Earth is almost a circle, the point in the sky towards which it is moving, called rather grandly the Apex of the Earth's Way, is roughly at right-angles to the line joining the Earth to the Sun, towards a point on the ecliptic to the west of the Sun. Thus if one faces the Sun at midday, the Apex is setting in the west, and it does not rise in the east until midnight. At dawn it is to the south, so that we can only look along the line of motion of the Earth against the background of stars between midnight and dawn. For this reason we see more meteors after midnight than before it, because it is only in the morning hours that we face the part of space through which the Earth is moving, sweeping up the meteoric dust.

September

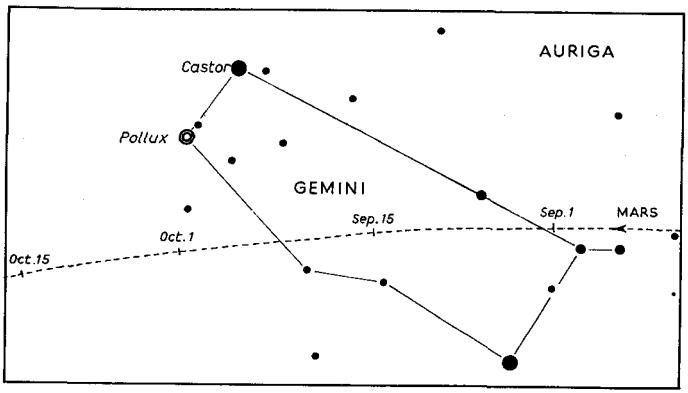
Full Moon: September 14 *New Moon:* September 28

EQUINOX: September 23.

MERCURY is at greatest elongation east (27 degrees) on September 10, but is then far south of the Sun, and is unlikely to be seen in the western sky at sunset.

VENUS is at greatest elongation east on September 3. Although it will then be 46 degrees from the Sun, it will be 12 degrees south of the equator, so that this is not a very favourable elongation, the planet setting only an hour after the Sun.

MARS now rises before midnight, and grows steadily brighter as it passes through the constellation of Gemini (see diagram below). At the end of September it forms a conspicuous group with the Twins, *Castor* and *Pollux*, which are of comparable brightness.



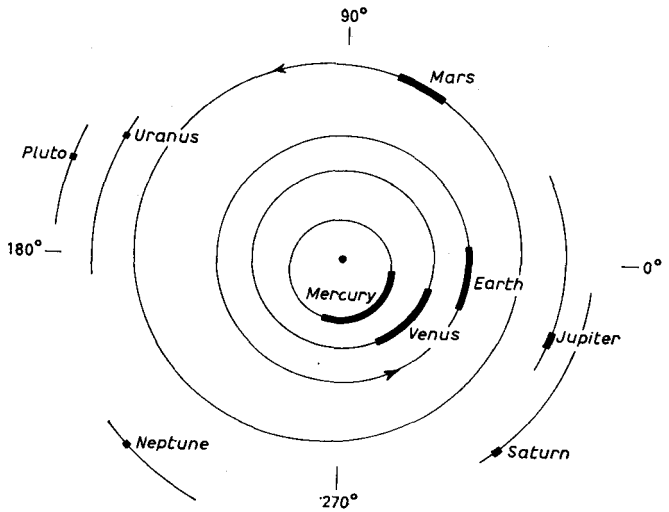
Mars

JUPITER is a brilliant evening star (magnitude −2·4), still moving retrograde in Aquarius. It is now only 10 degrees south of

the equator, and may thus reach an altitude of nearly 30 degrees in southern England – much higher than it has been for some years.

SATURN will be seen in the south in mid-evening, among the stars of Capricornus. The planet fades to magnitude +0·7 by the end of September.

The Full Moon of September 14 will be at perigee, the distance from the centre of the Earth to the centre of the Moon being then about 222,000 miles. This is only about seven-eighths of the distance at apogee, as at the Full Moon of February, which was 253,000 miles from the Earth. The change in the apparent size of the Moon is seldom obvious to the naked eye, which is a very poor judge of such matters.



Planetary orbits in September

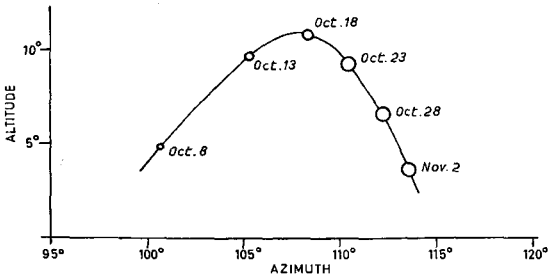
The Harvest Moon. The Full Moon of September is generally referred to as the Harvest Moon, although the term is more properly

applied to the Full Moon which occurs nearest to the autumnal equinox, and which may, therefore, come in October. For several nights in succession at this time of year the Moon rises only a few minutes later each evening, the delay from night to night being noticeably less than usual. The phenomenon of the Harvest Moon is repeated to a less extent at the following Full Moon (called the 'Hunter's Moon') and is caused by the phenomenon, already explained, that on autumn evenings the ecliptic is at its lowest in the sky and is inclined at a very shallow angle to the horizon. The daily motion of the Moon is about 13 degrees, and if the Moon's path were perpendicular to the horizon, moonrise would be delayed from night to night by the time taken by the Earth to turn through 13 degrees, that is, by 52 minutes. If the angle which the Moon's path makes with the horizon is small, then the delay is much reduced, and in favourable conditions may be only about 9 minutes. Since the Moon travels right round the sky once a month, the effect occurs every month, but our attention is drawn to it most effectively at the time of Full Moon, which rises at the convenient time of sunset. It is thus in the autumn months that we are aware that there is more moonlight than usual, a fact that was of benefit to the farmer in the days before tractors with headlamps. The interval between the times of moonrise at the time of the 1962 Harvest Moon will not be a minimum, but will reach about 26 minutes in southern England and about 19 minutes in northern Scotland. It should be remarked that there is no Harvest Moon in the tropics, while the phenomenon occurs in March in the southern hemisphere.

October

Full Moon: October 13 *New Moon:* October 28

MERCURY will be at inferior conjunction on October 6, and will not be seen during the first part of the month. The planet moves out to greatest western elongation on October 22, when it will be well north of the Sun, and favourably placed for observation as a morning star. The diagram shows the changes in altitude and azimuth of Mercury at the time when the Sun is 6 degrees below the horizon – approximately 35 minutes before sunrise on the dates shown. In this case a clear horizon to the south of east will be essential. The changes in the brightness of the planet are indicated approximately by the size of the circles; it will be seen that Mercury is brightest after the date of greatest elongation.



Mercury

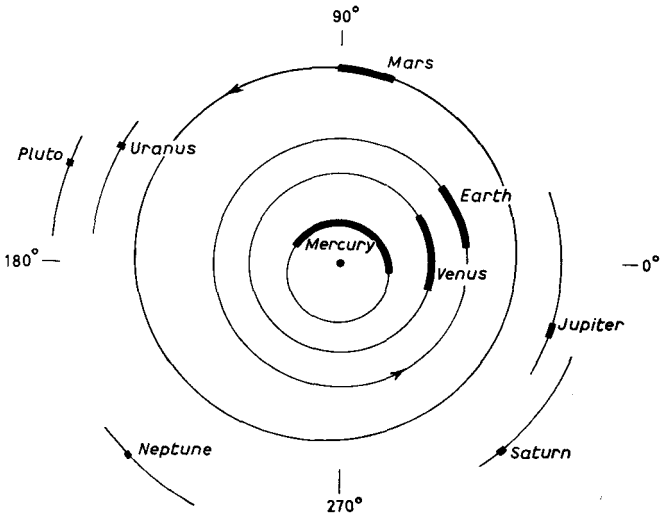
VENUS will reach its greatest brilliancy (magnitude −4·3) on October 8, but it is then about 26 degrees south of the equator, and will be visible for only a short time after sunset. In a small telescope, the planet now presents the appearance of a crescent, similar to that of the Moon a few days after New Moon.

MARS now rises rather more than an hour before midnight, and at the end of October will be in the south at dawn. The brightness of the planet increases to magnitude +0·8, and Mars is a conspicuous object in Cancer, a part of the sky which does not possess

many bright stars. Mars passes close to the star cluster Præsepe about October 25.

JUPITER is at a stationary point on October 29 (see diagram on page 29) by which time it will have faded a little, to magnitude −2·2. It will then be in the south in the early evening, and will set shortly after midnight.

SATURN is an evening star, setting at midnight at the beginning of October, and about two hours earlier at the end. The planet is still a bright object (magnitude +0·8), and is at a stationary point on October 9, when it will be seen in Capricornus, in a line below the stars Alpha and Beta. After this date, Saturn continues its direct motion towards the east.



Planetary orbits in October

The star cluster Præsepe. About October 23, the planet Mars will be seen close to the star cluster *Præsepe* in the constellation of Cancer. This is a barren part of the sky, but even without the

planet Mars to act as a guide, the cluster is easily found. About midway between *Regulus* in Leo and the Twins *Castor* and *Pollux*, there are two small stars with a hazy patch of light between them; this hazy object is *Præsepe*, and any small glass – even an opera glass – will show that it is composed of stars. This pretty little group is sometimes called the Beehive, because of its shape, but the word *Præsepe* means a fold or manger, and to the ancients it represented a bundle of hay, while the two stars were the ass's colts who helped the gods in their fight with the giants. The northern star, Gamma Cancri, is named *Asellus Borealis* in the old star atlases, while the southern star, Delta Cancri, is *Asellus Australis*. Ptolemy has recorded that this star was occulted by Jupiter on the night of September 3 in the year 240 B.C., and this is probably the earliest recorded observation of a position of this planet. *Præsepe*, which lies quite close to the ecliptic, was naturally well known to the ancient astronomers because of their naked-eye observations of the planets. As a result, it was often used as a weather sign – a familiar kind of sign, as given in a translation of one of the poems of Aratus:

A murky manger with both stars
Shining unaltered is a sign of rain.

This star cluster contains about 100 stars and is at a distance of nearly 500 light-years. It is, of course, visible at more convenient hours in the spring months.

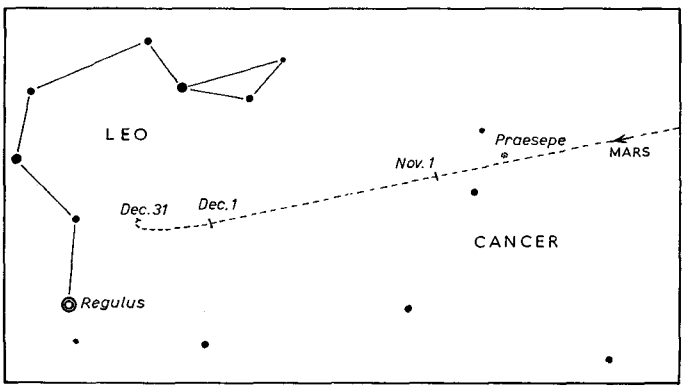
November

Full Moon: November 11 *New Moon:* November 27

MERCURY is at superior conjunction on November 25, and will not be seen this month.

VENUS is at inferior conjunction on November 12, and will then be about 25 million miles from the Earth. The planet will not be visible to the naked eye at this time, but the inclination of its orbit carries it some $4\frac{1}{2}$ degrees south of the Sun, and it would be visible in a telescope as a fine slender crescent. Venus moves north again after conjunction, coming rapidly out from the Sun, and by the end of the month it will be seen as a brilliant morning star, rising in the south-east nearly two hours before dawn.

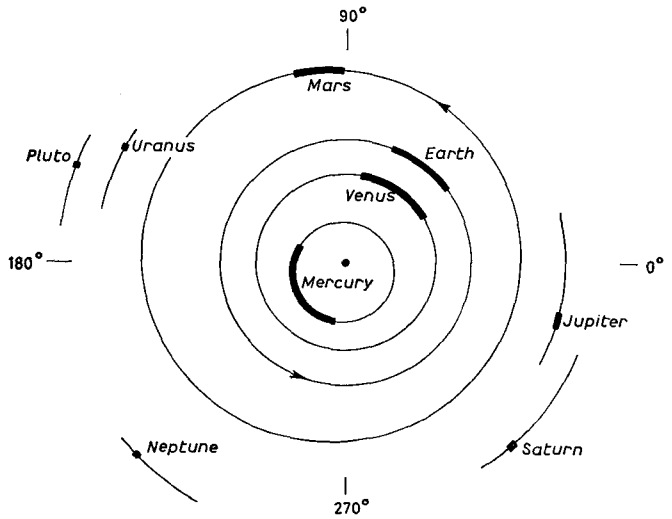
MARS moves from Cancer into Leo, and approaches *Regulus*, but its motion will not take it as far as this star during the present season. The brightness of the planet is now increasing rapidly, the magnitude changing from +0·8 to +0·3 during the month, as the distance from the Earth decreases. Mars now rises well before midnight. The diagram shows the apparent path of Mars among the stars of Cancer and Leo, from mid-October to the end of the year.



Mars

JUPITER is still a brilliant evening star, and is now moving direct again. It will be seen in the south-west just after sunset, and sets before midnight at the end of November.

SATURN is an evening star, setting at about 22^h at the beginning of the month, and at 20^h at the end. It is now half a magnitude fainter than it was at opposition. There is an interesting occultation of Saturn on the night of November 4, when the Moon, nearly at First Quarter, passes in front of the planet at about $19^h\ 23^m$. Saturn will vanish behind the extreme northern point of the dark limb of the Moon, and will reappear nearly 20 minutes later from behind the bright limb. The whole spectacle may be watched with the naked eye, but may be more easily followed with binoculars or a small telescope, which will render the reappearance more easily visible. This phenomenon is only visible in southern England and, perhaps, the Midlands; in Scotland the planet will be seen to make a very close approach to the Moon's northern edge.



Planetary orbits in November

Venus and the solar parallax. At the inferior conjunction of Venus in April 1961, when the planet was at its closest to the Earth, attempts were made to find its accurate distance from us by radar methods, and hence to deduce our own distance from the Sun. Since the relative sizes of the planetary orbits are known with considerable accuracy, a measurement of the distance between any two of them enables the scale of the solar system to be fixed. Experiments at the Millstone Radar Observatory of the Massachusetts Institute of Technology (situated at Westford, Mass.), gave as a value of the solar parallax 8·79450 seconds of arc, leading to a figure of 92,956,000 miles for the astronomical unit. Similar experiments at Jodrell Bank, near Manchester, gave an almost identical result of 8″·7943 for the solar parallax, or 92,958,000 miles for the distance of the Earth from the Sun. These are the most accurate direct measurements of the distance that have yet been made, but they do not agree with the values adopted by astronomers. The previous best astronomical values were 8″·7984 and 92,915,000 miles. It must be remembered that the new radar measurements depend on a number of assumptions as to the velocity of radio waves in free space, and the dimensions of the planets, and cannot be regarded as the last word on the subject.

December

Full Moon: December 11 *New Moon:* December 26

SOLSTICE: December 22.

MERCURY was at superior conjunction at the end of November, and will not be visible this month. Greatest elongation east occurs on January 4, 1963, when Mercury again becomes an evening star.

VENUS is a brilliant object in the dawn sky, attaining its greatest brilliancy on December 19; magnitude −4·4. The telescopic appearance at this time is similar to that of the crescent Moon a few days after Last Quarter, i.e., the horns of the crescent point to the west. At the end of the month Venus rises in the south-east more than three hours before dawn – a splendid object among the stars of Libra.

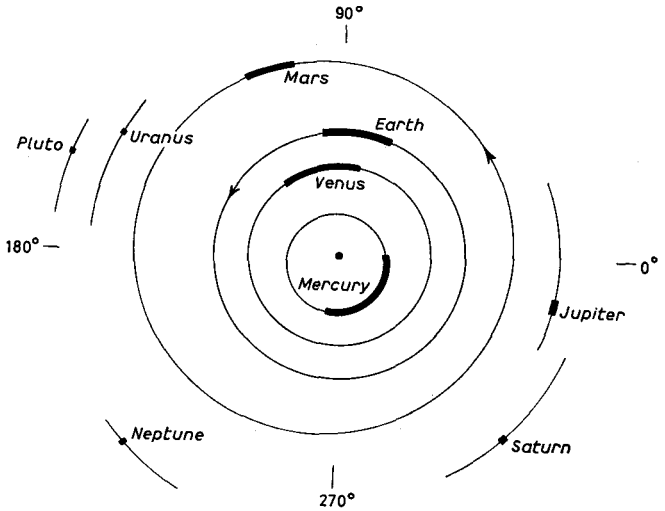
Venus will be at greatest elongation as a morning star on January 23, 1963.

MARS is now growing rapidly brighter and at the end of the year reaches magnitude −0·4. Its motion to the east becomes slower, and it reaches a stationary point to the west of *Regulus* on December 27. Mars will remain in this part of the sky for the next few months, forming an attractive group with the stars of the Sickle of Leo, but conspicuous among them by reason of its colour and brilliance. The next opposition occurs on February 4, 1963, when its distance from the Earth will be 62 million miles.

JUPITER now sets in the south-west in mid-evening. Although not as bright as it was in August, it is still a brilliant object (magnitude −1·8) and is easily recognized below the stars Alpha and Beta of Pegasus. Jupiter is moving direct, and is again approaching the star Lambda Aquarii; it will pass it for the third time in January 1963, about ¾ degree south of the star on this occasion. In the

spring of next year, Jupiter will cross the equator and then continue in northern declinations for another six years.

SATURN will be seen low in the south-west in the early evening; it sets at about 20^h at the beginning of the month. The next opposition of Saturn takes place in August 1963, when the planet will still be seen in Capricornus.



Planetary orbits in December

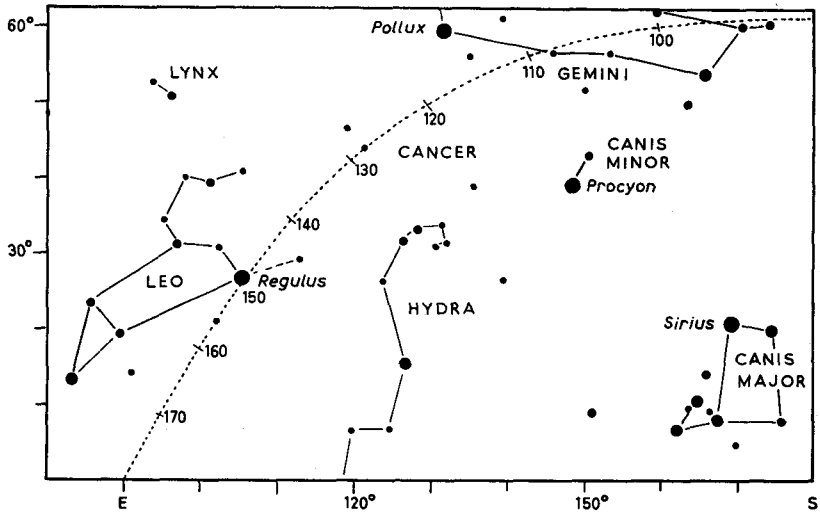
Star clusters. A great deal of research in astronomy is directed at the present time to study of star clusters. This work has the advantage that all the stars in a cluster are at about the same distance from us, so that they can be studied under similar conditions; for example, their apparent brightness is at once a measure of their real luminosity, since there are no distance-effects. The beautiful cluster called the Pleiades is a typical example of the loose, or open cluster, of which about 400 are known. These have no regular shape, contain at most a few hundred stars, and are always found in or near the Milky Way. In such a cluster, the stars move through

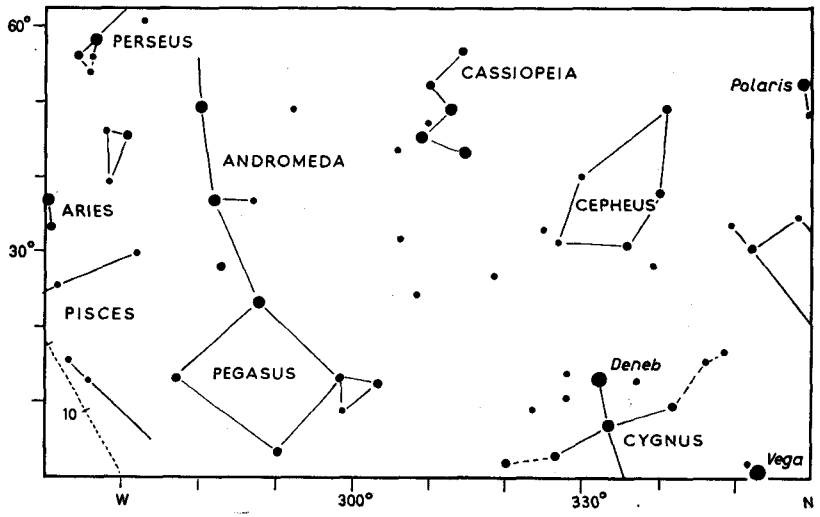
space as a unit, all sharing the same motion, so that they travel in parallel paths. In the course of their long journey round the Galaxy – a journey that may take several hundred million years – the cluster will be disturbed, not only by the attraction of the great mass of stars in the Galaxy, but also by chance encounters with passing stars. As a result the cluster will be broken up, and the rate at which this occurs will depend on how tightly the stars were packed in the cluster in the first place. It has been calculated that most clusters of this kind would be disrupted completely in the course of one or two trips round the Galaxy. Thus we know that the open clusters as we see them today could not have been in existence when the majority of the stars of the Galaxy were formed some thousands of millions of years ago.

The Pleiades consist of about 250 stars, packed in a space about twenty light-years across, and about 400 light-years from us. Most of the stars are hot blue-white stars, so hot that they excite the cloud of dust and gas that surrounds them, and the stars are therefore seen to be immersed in a glowing nebula. The nearby cluster of the Hyades is a larger group, packed less tightly, and only about 100 light-years away. About 100 stars are known to belong to the Hyades cluster, but *Aldebaran* is not one of them – this bright star is in the foreground, only about half as far away. All the Hyades are moving towards a point in Orion at a speed of about 27 miles a second. The cluster is very different from the Pleiades. There is no dust or gas here, and no brilliant blue-white stars, but there are some red giant stars. The Hyades is an old cluster, and if it was once packed as closely as the Pleiades, it has been disrupted since then.

1L

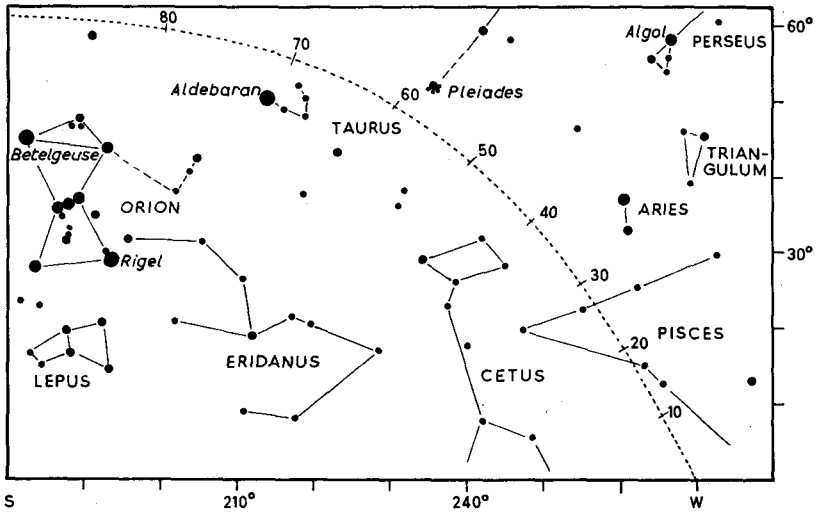
October 6 at	5^h	October 21 at	4^h
November 6 at	3^h	November 21 at	2^h
December 6 at	1^h	December 21 at	midnight
January 6 at	23^h	January 21 at	22^h
February 6 at	21^h	February 21 at	20^h

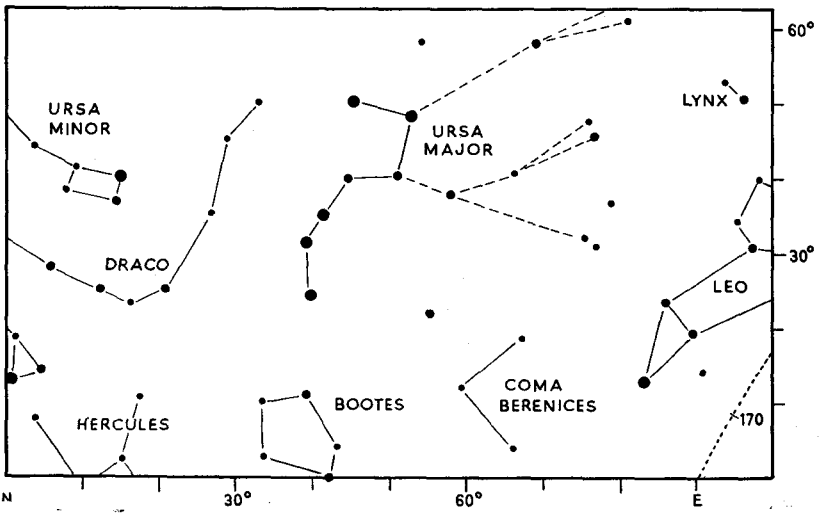




October 6 at	5h	October 21 at	4h
November 6 at	3h	November 21 at	2h
December 6 at	1h	December 21 at	midnight
January 6 at	23h	January 21 at	22h
February 6 at	21h	February 21 at	20h

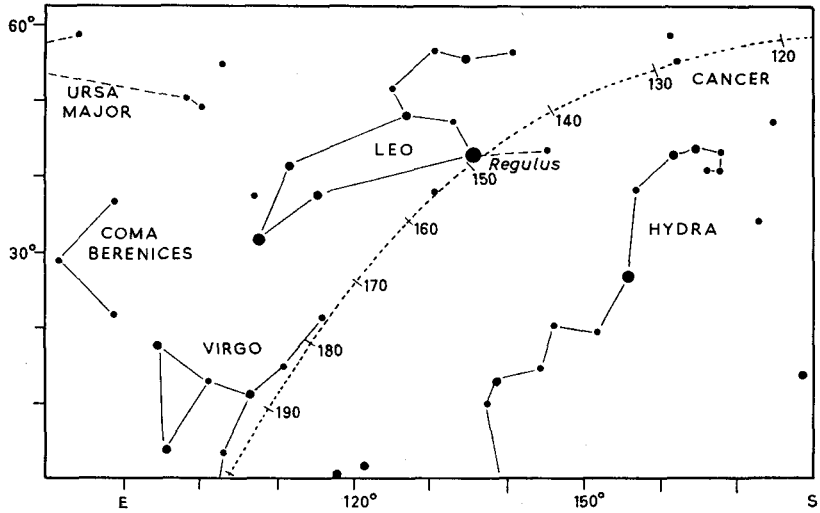
1R

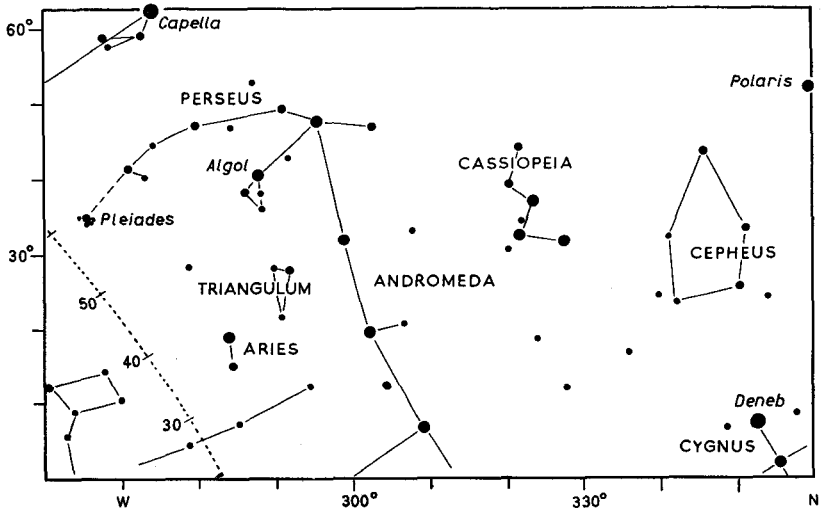




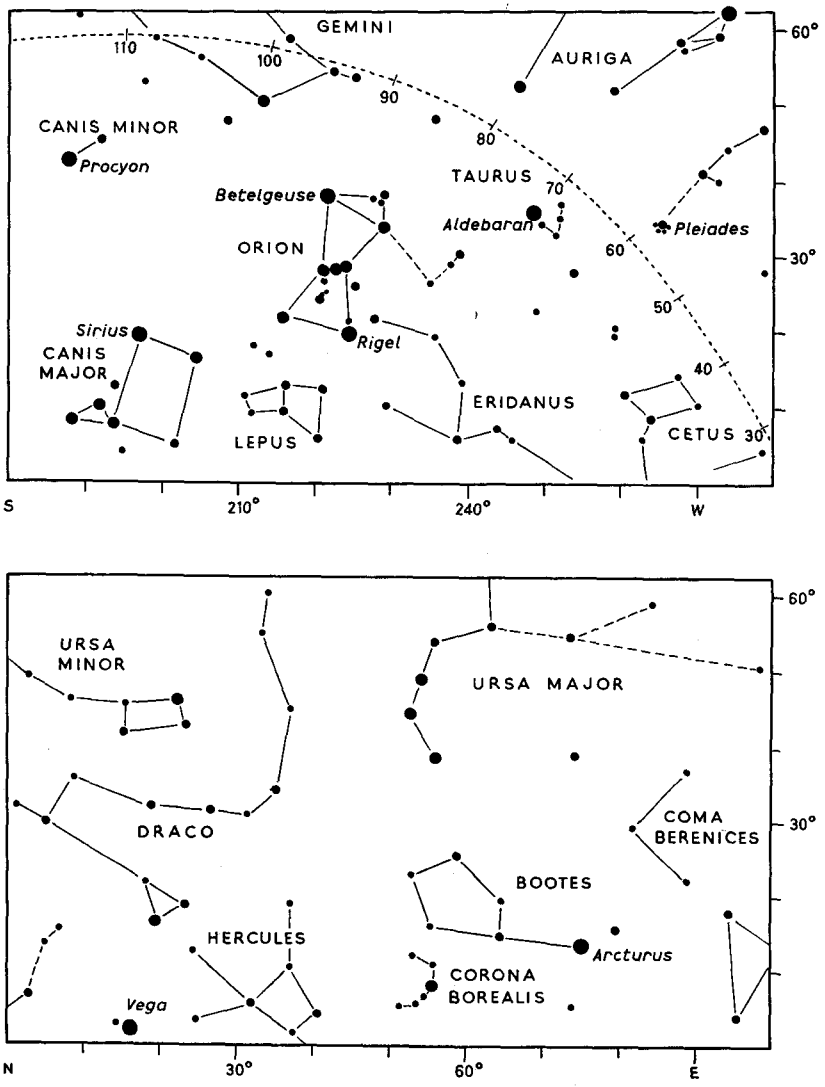
2L

November 6 at 5^h	November 21 at 4^h
December 6 at 3^h	December 21 at 2^h
January 6 at 1^h	January 21 at midnight
February 6 at 23^h	February 21 at 22^h
March 6 at 21^h	March 21 at 20^h



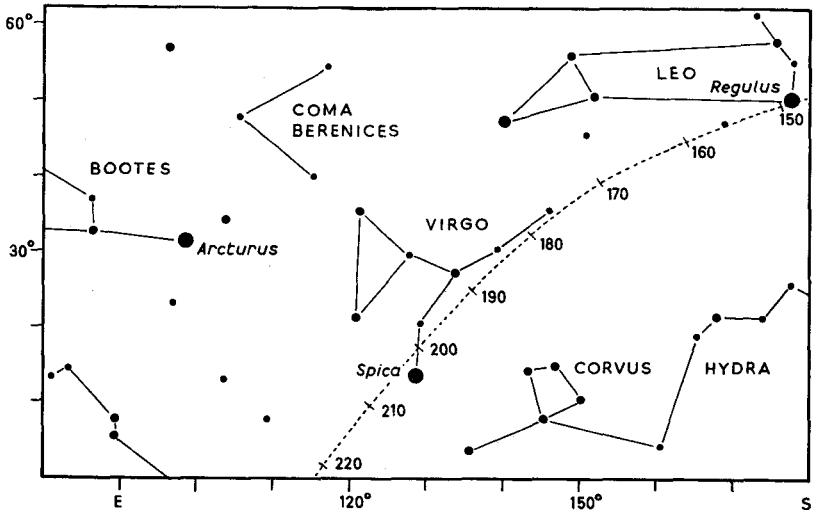


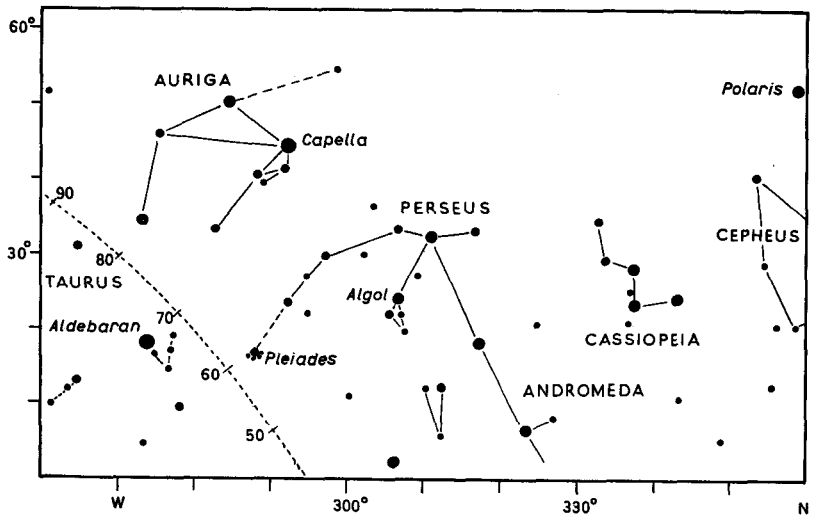
November 6 at 5h	November 21 at 4h	**2R**
December 6 at 3h	December 21 at 2h	
January 6 at 1h	January 21 at midnight	
February 6 at 23h	February 21 at 22h	
March 6 at 21h	March 21 at 20h	



3L

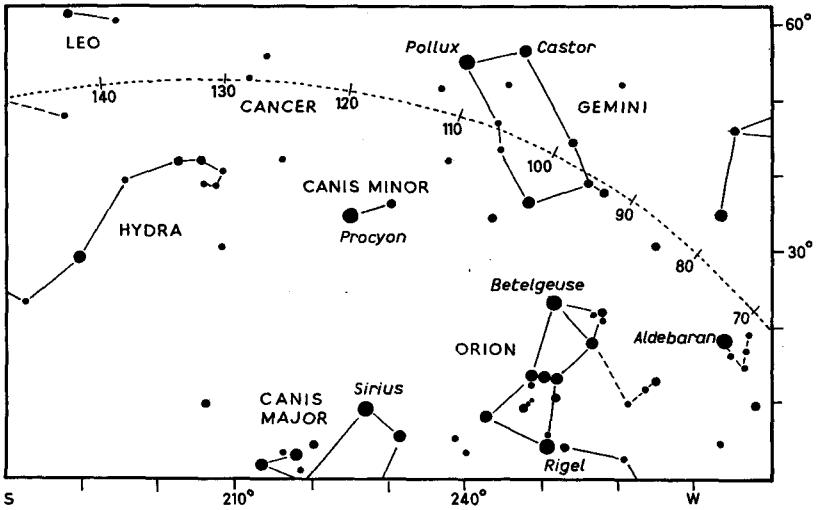
December 6 at 5h	December 21 at 4h
January 6 at 3h	January 21 at 2h
February 6 at 1h	February 21 at midnight
March 6 at 23h	March 21 at 22h
April 6 at 21h	April 21 at 20h

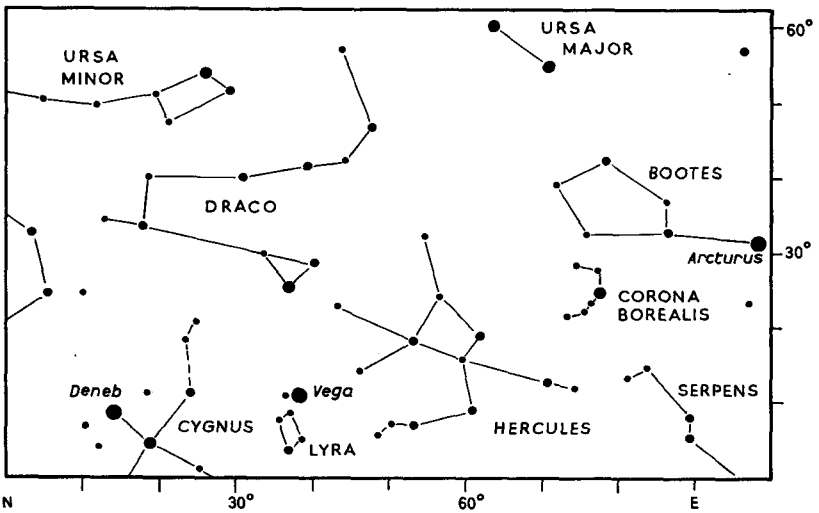




December 6 at 5h	December 21 at 4h
January 6 at 3h	January 21 at 2h
February 6 at 1h	February 21 at midnight
March 6 at 23h	March 21 at 22h
April 6 at 21h	April 21 at 20h

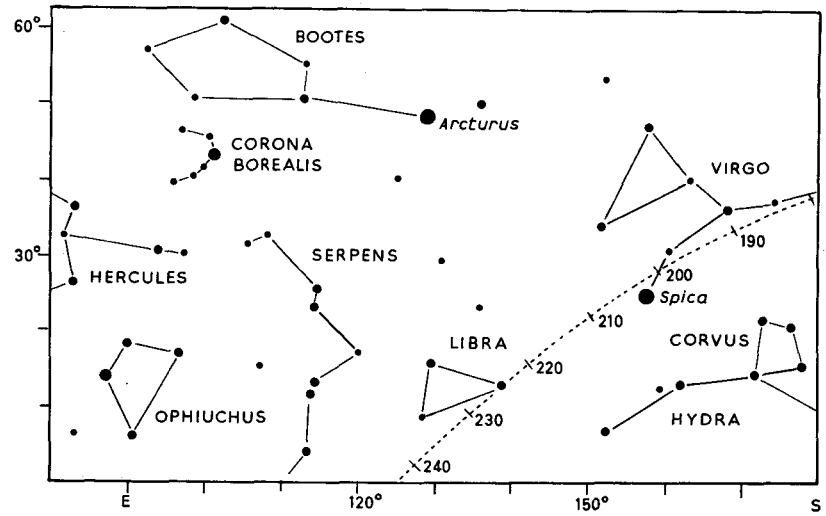
3R

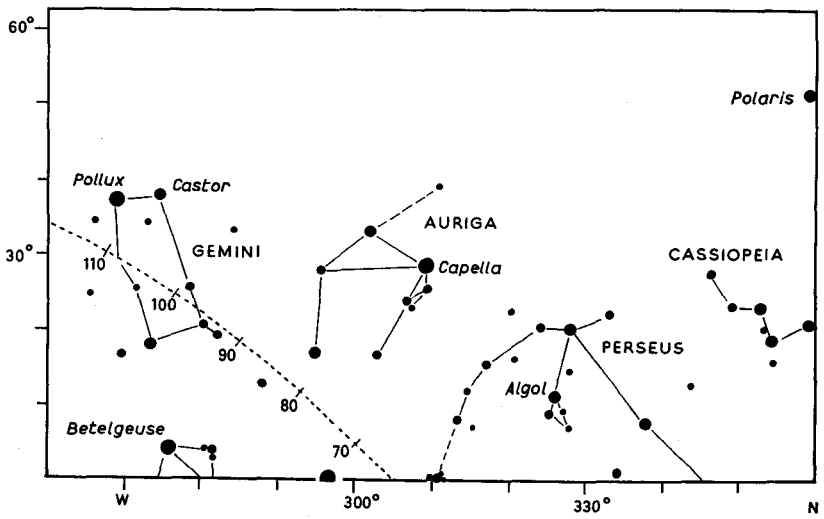




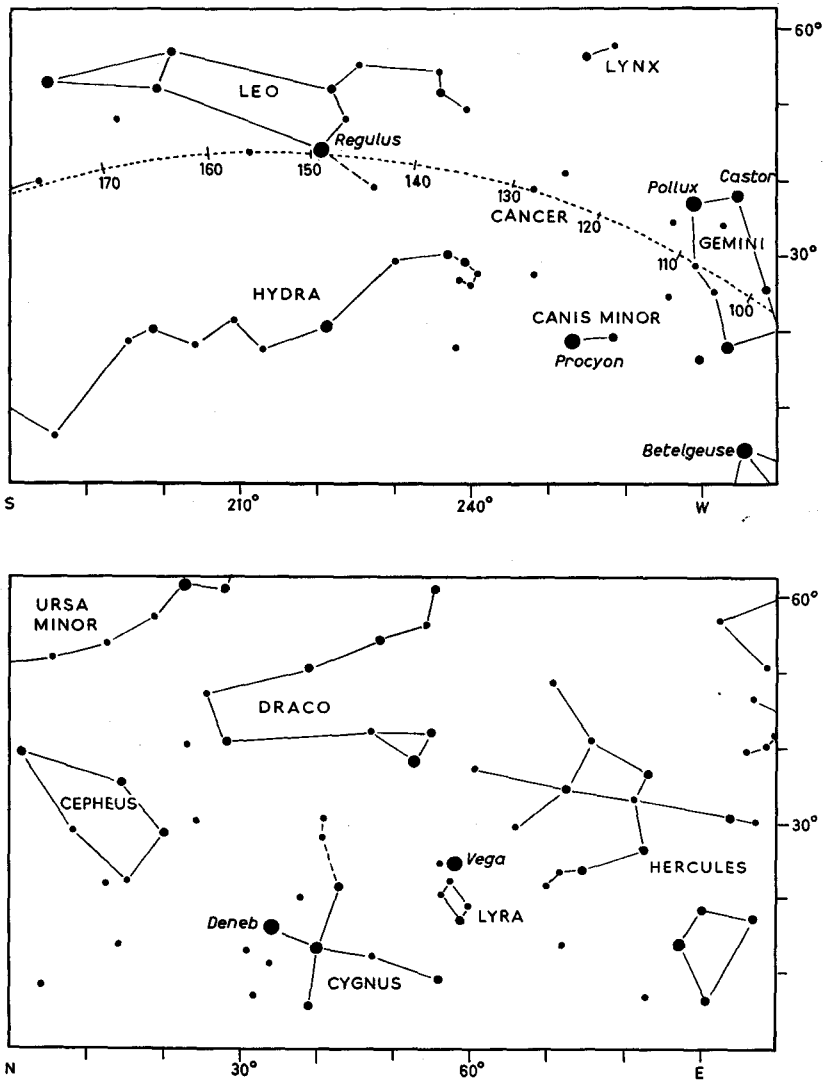
4L

January 6 at 5h	January 21 at 4h
February 6 at 3h	February 21 at 2h
March 6 at 1h	March 21 at midnight
April 6 at 23h	April 21 at 22h
May 6 at 21h	May 21 at 20h



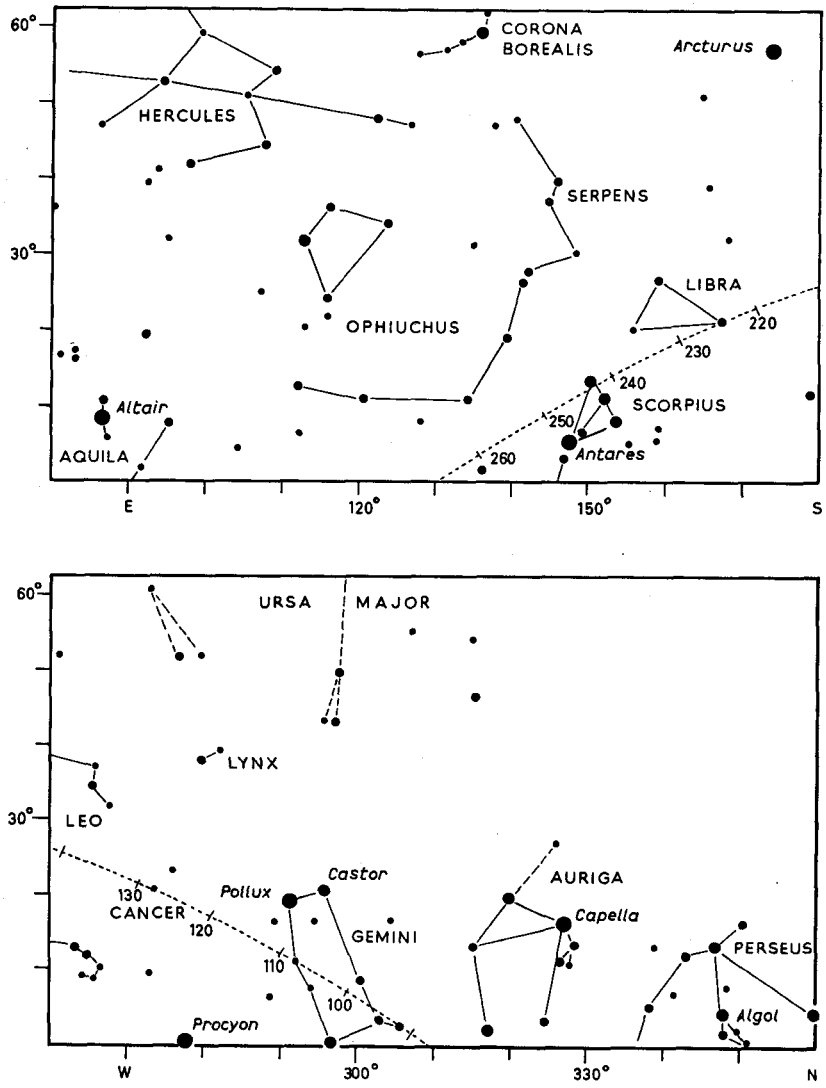


January 6 at 5h	January 21 at 4h	**4R**
February 6 at 3h	February 21 at 2h	
March 6 at 1h	March 21 at midnight	
April 6 at 23h	April 21 at 22h	
May 6 at 21h	May 21 at 20h	

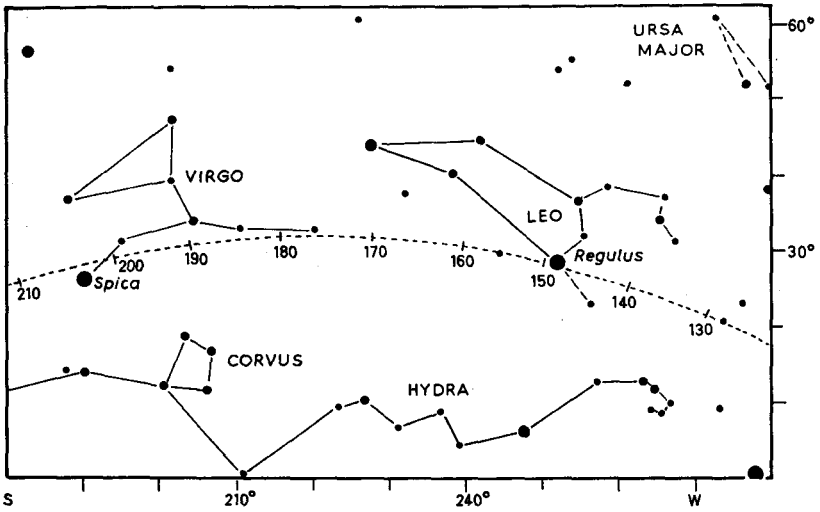


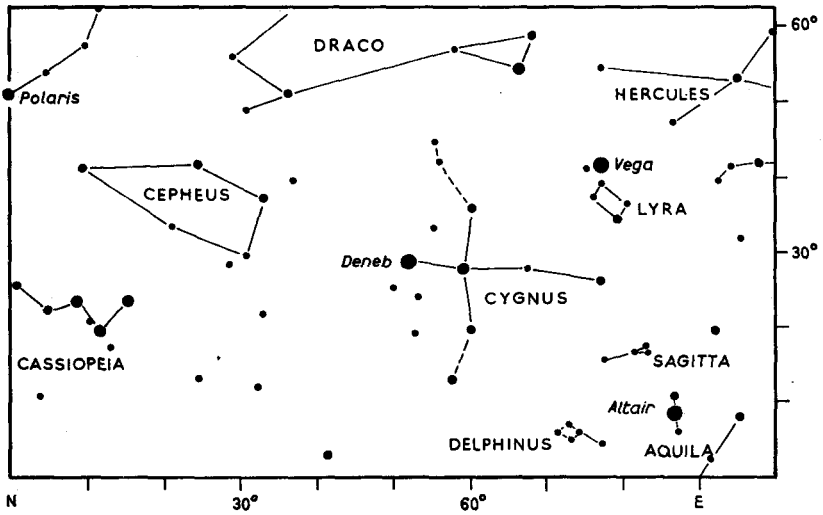
5L

January 6 at	7^h	January 21 at	6^h
February 6 at	5^h	February 21 at	4^h
March 6 at	3^h	March 21 at	2^h
April 6 at	1^h	April 21 at	midnight
May 6 at	23^h	May 21 at	22^h



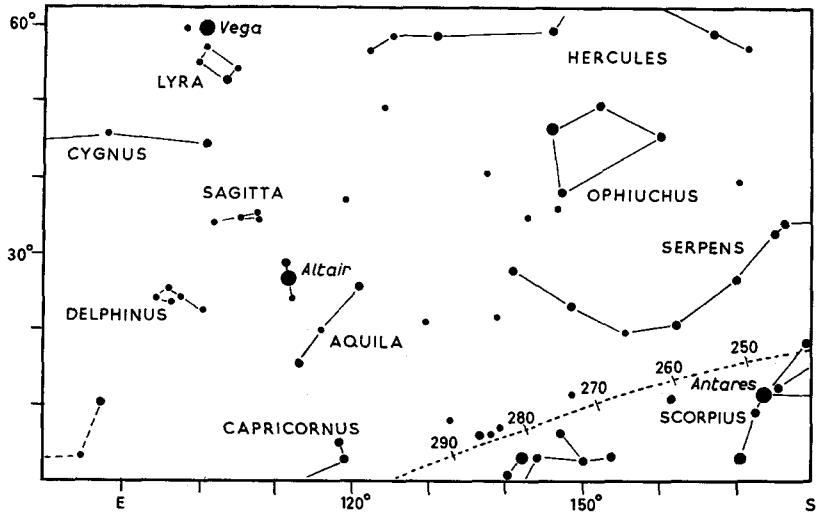
January 6 at 7h	January 21 at 6h	**5R**
February 6 at 5h	February 21 at 4h	
March 6 at 3h	March 21 at 2h	
April 6 at 1h	April 21 at midnight	
May 6 at 23h	May 21 at 22h	

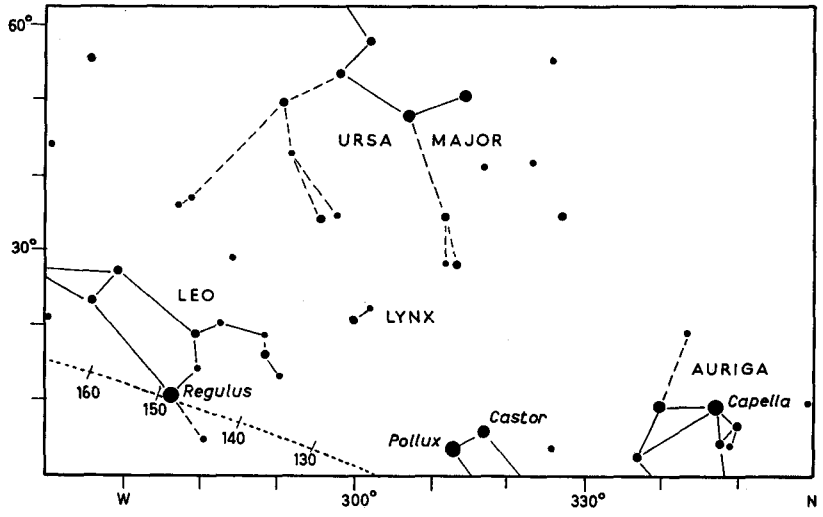




6L

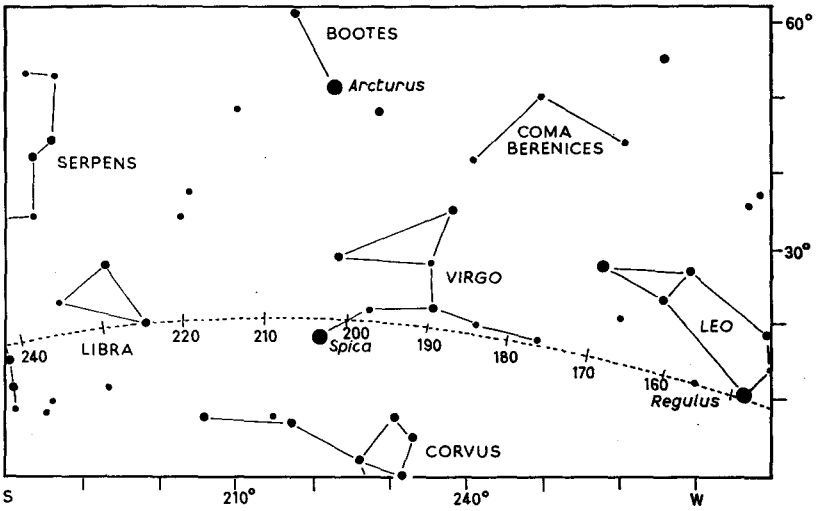
March 6 at 5h	March 21 at 4h
April 6 at 3h	April 21 at 2h
May 6 at 1h	May 21 at midnight
June 6 at 23h	June 21 at 22h
July 6 at 21h	July 21 at 20h

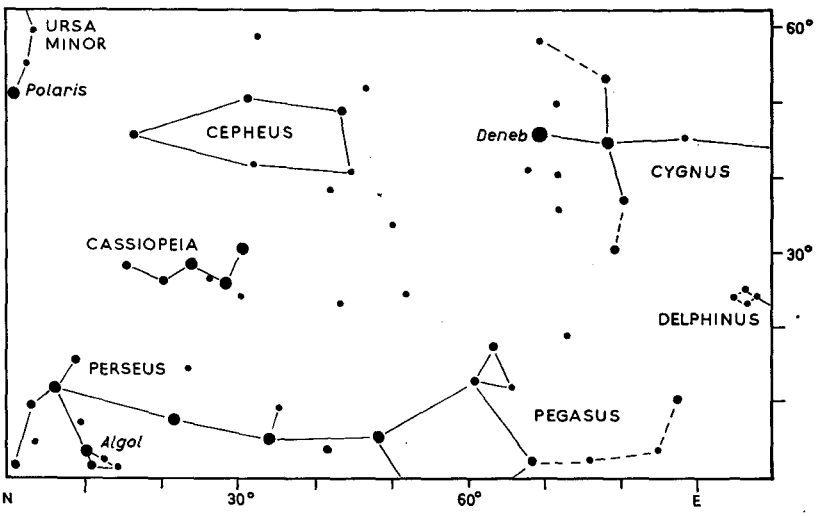




March 6 at	5^h	March 21 at	4^h
April 6 at	3^h	April 21 at	2^h
May 6 at	1^h	May 21 at	midnight
June 6 at	23^h	June 21 at	22^h
July 6 at	21^h	July 21 at	20^h

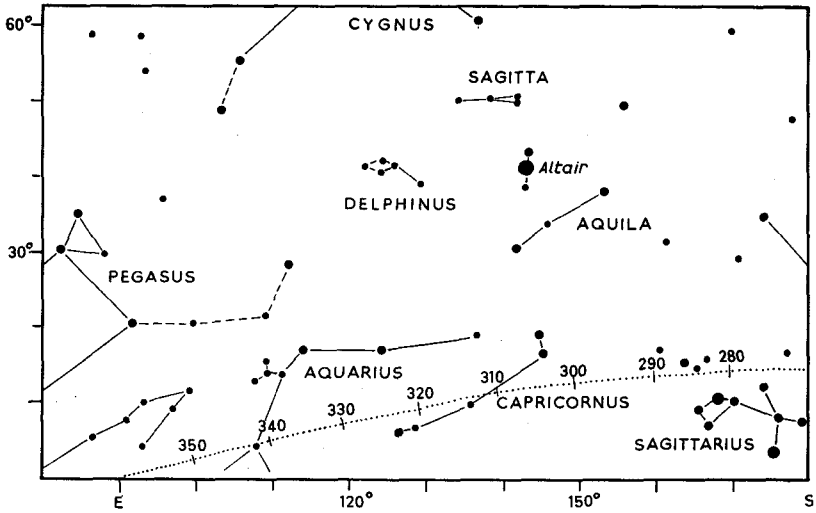
6R

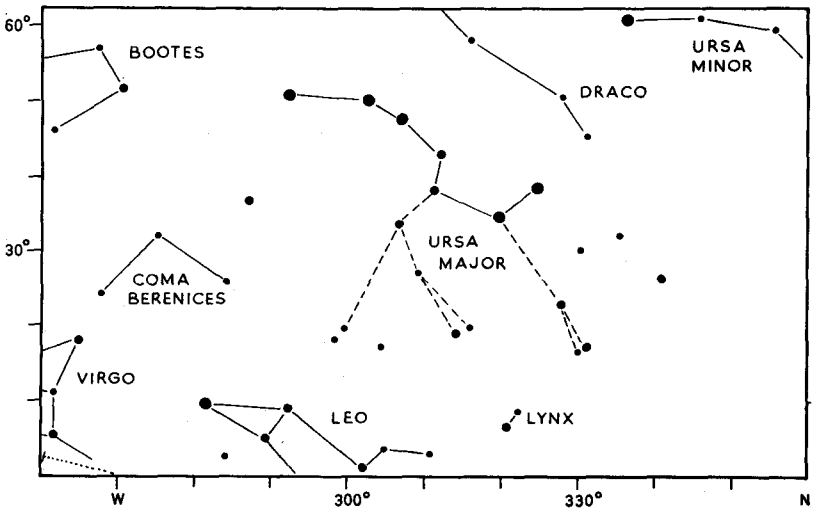




7L

May 6 at 3h	May 21 at 2h
June 6 at 1h	June 21 at midnight
July 6 at 23h	July 21 at 22h
August 6 at 21h	August 21 at 20h
September 6 at 19h	September 21 at 18h





May 6 at 3h	May 21 at 2h	**7R**
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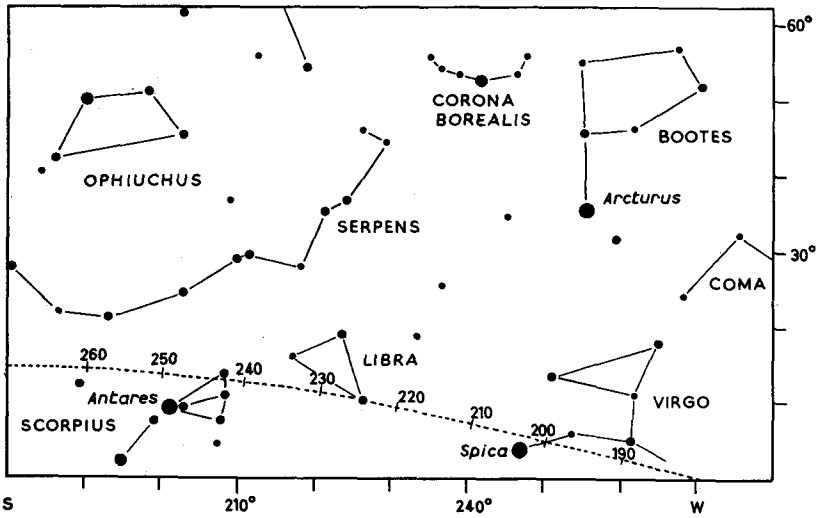
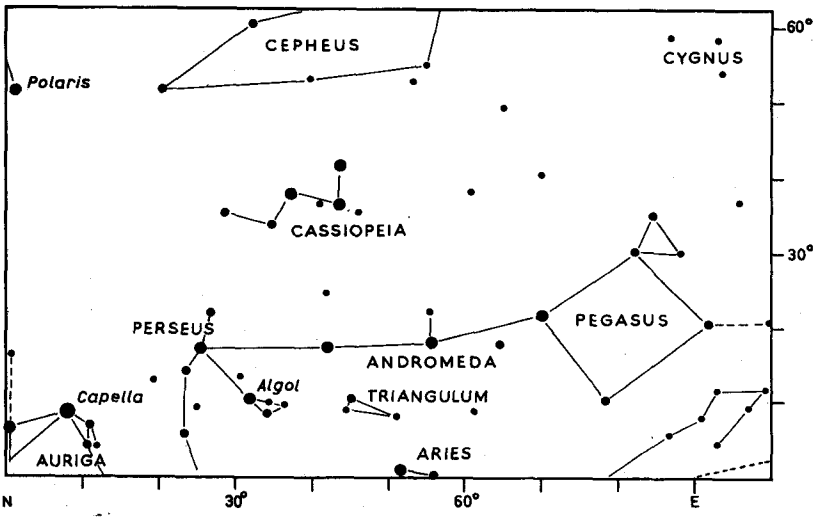
August 6 at 21h	August 21 at 20h	
September 6 at 19h	September 21 at 18h	





8L

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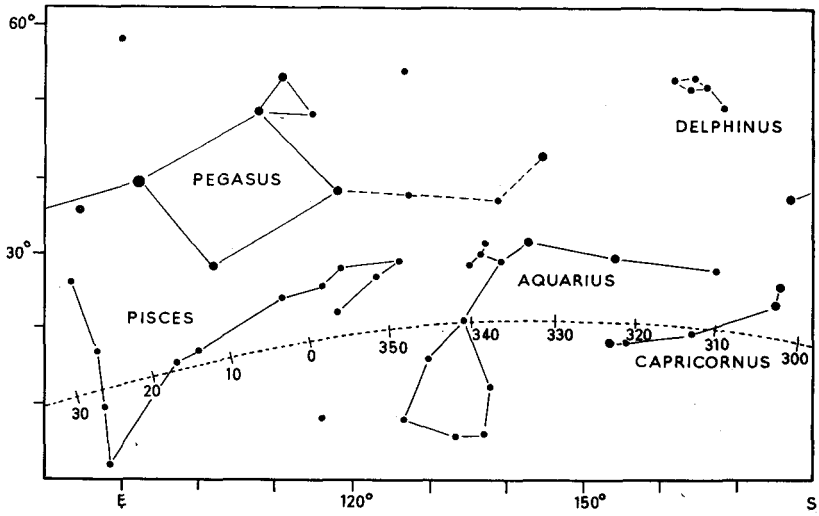
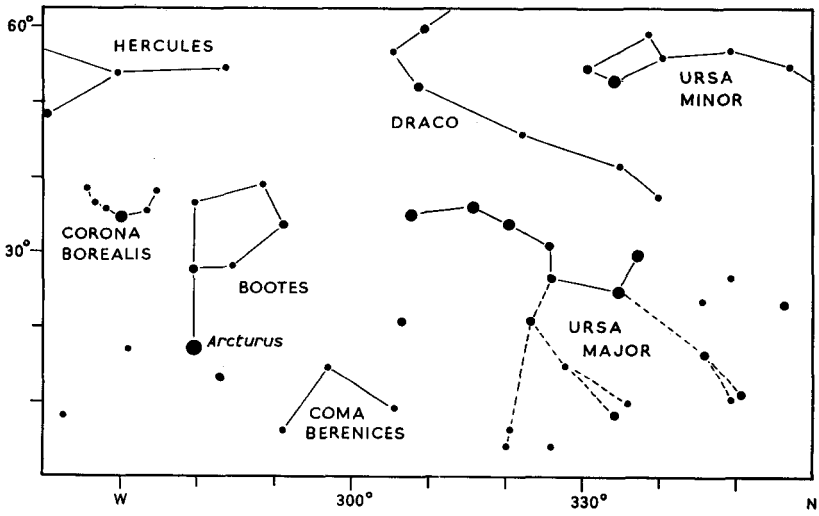
September 6 at 21h	September 21 at 20h
October 6 at 19h	October 21 at 18h
November 6 at 17h	November 21 at 16h





July 6 at 1h
August 6 at 23h
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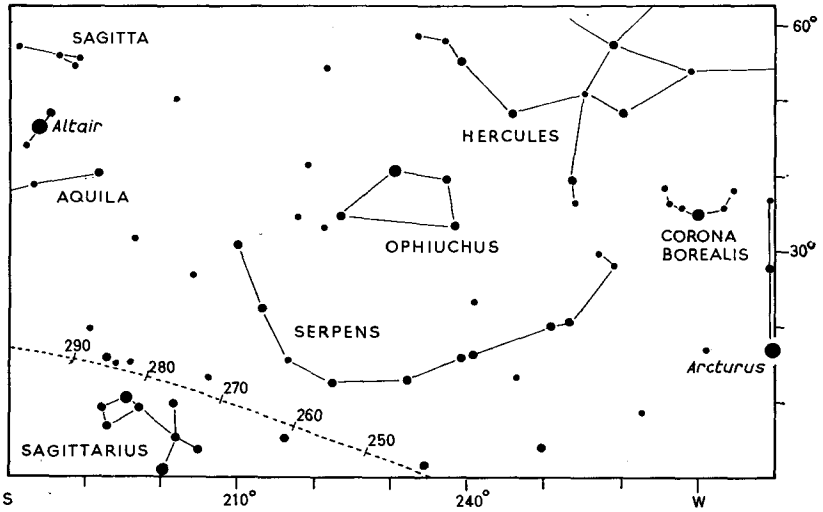
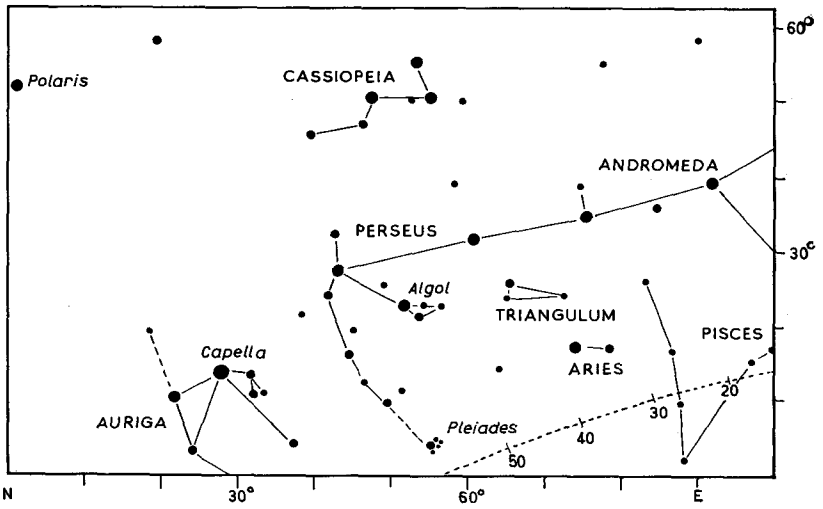
November 6 at 17h

July 21 at midnight
August 21 at 22h
September 21 at 20h
October 21 at 18h
November 21 at 16h

8R





9L

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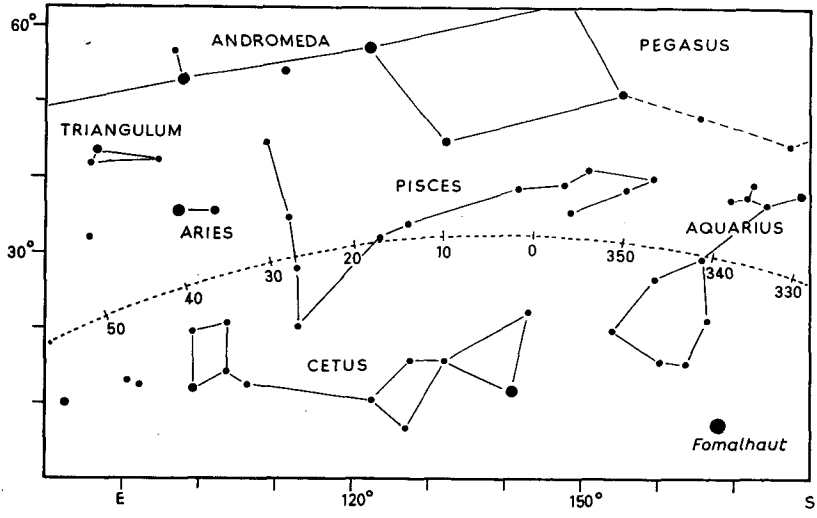
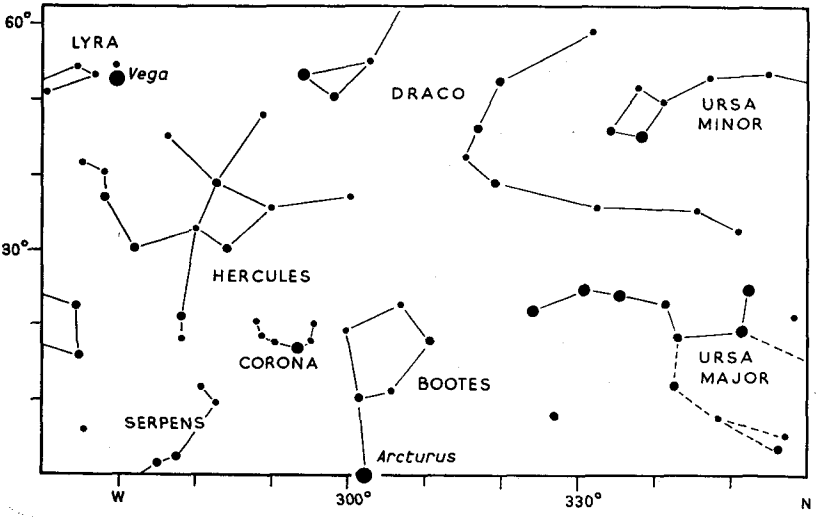
November 6 at 19h	November 21 at 18h
December 6 at 17h	December 21 at 16h





August 6 at 1h	August 21 at midnight
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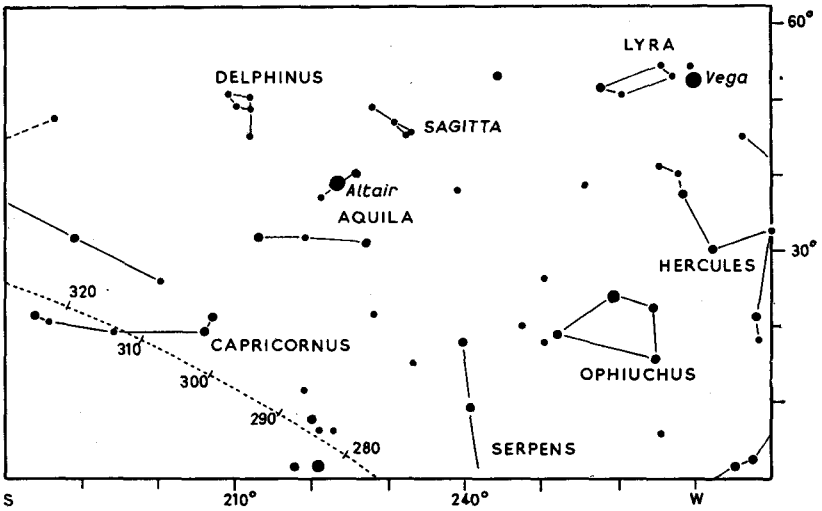
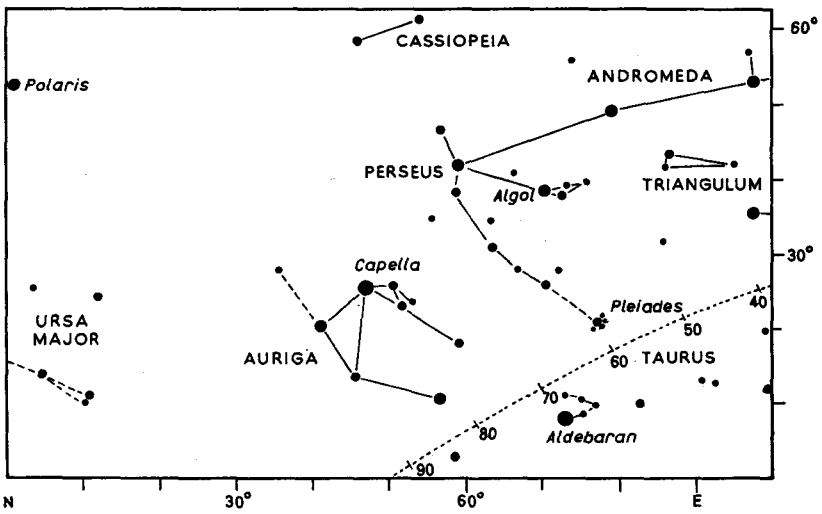
November 6 at 19h	November 21 at 18h
December 6 at 17h	December 21 at 16h

9R





10L

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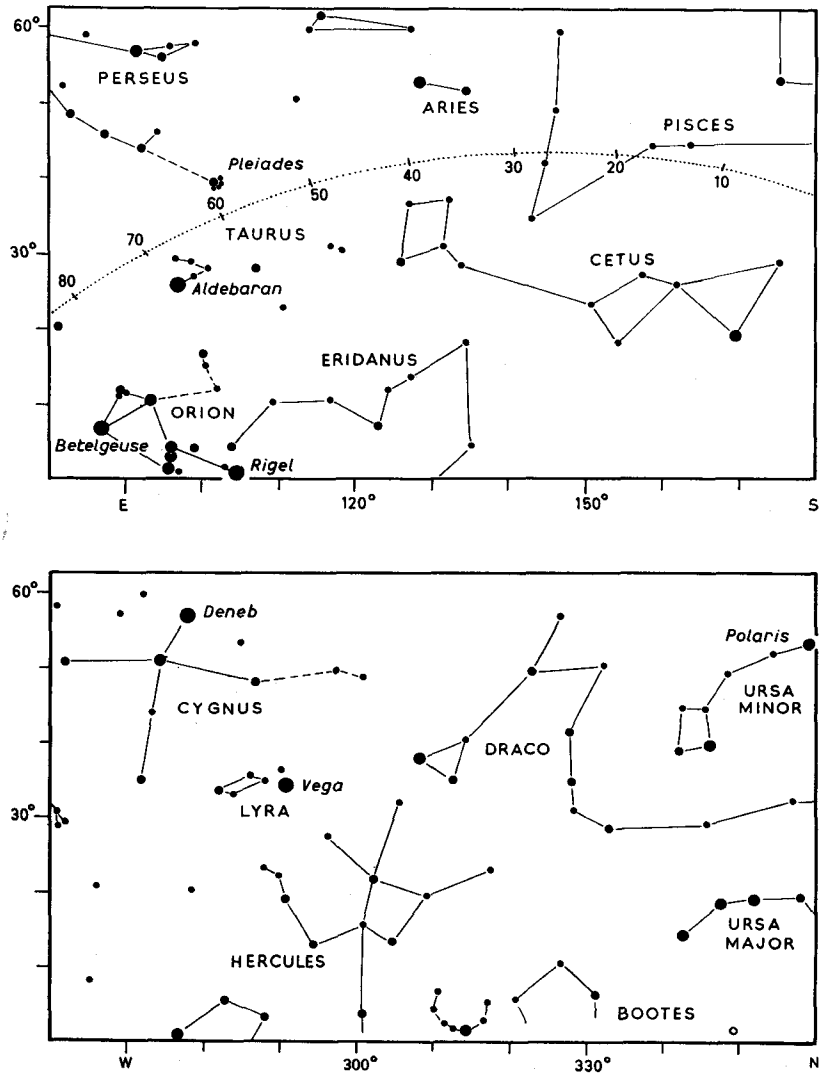
December 6 at 19h	December 21 at 18h



August 6 at 3h	August 21 at 2h	**10R**
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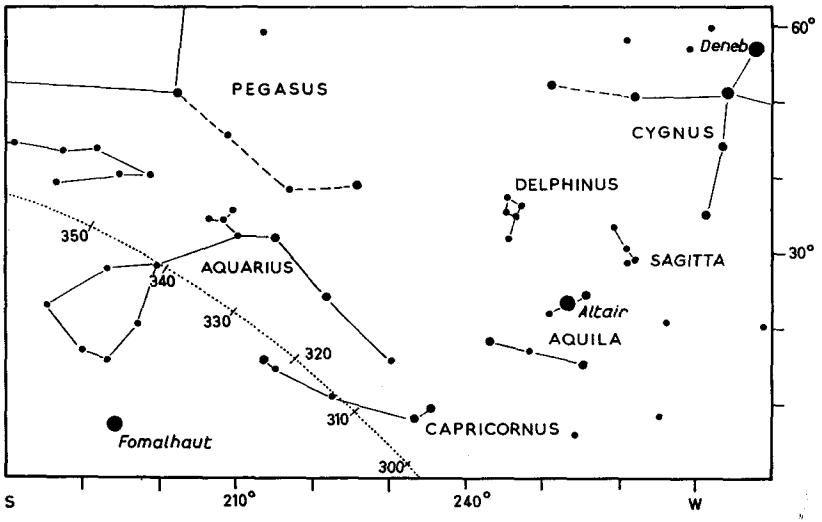
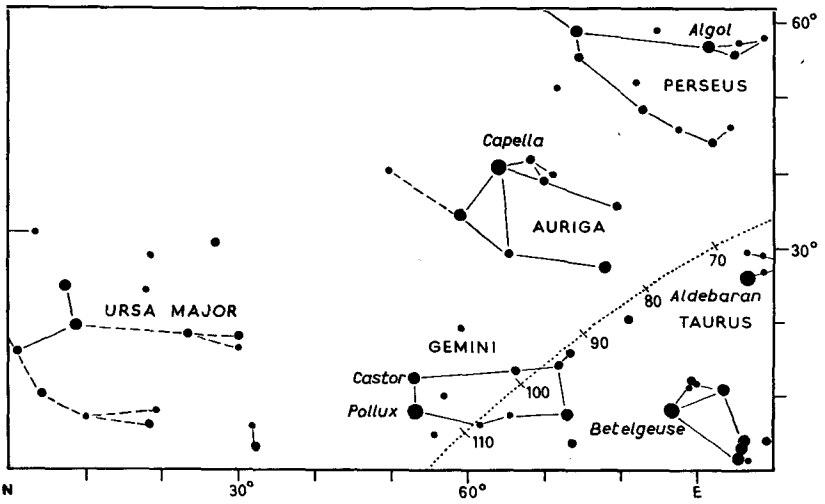
December 6 at 19h	December 21 at 18h	





11L

September 6 at 3h	September 21 at 2h
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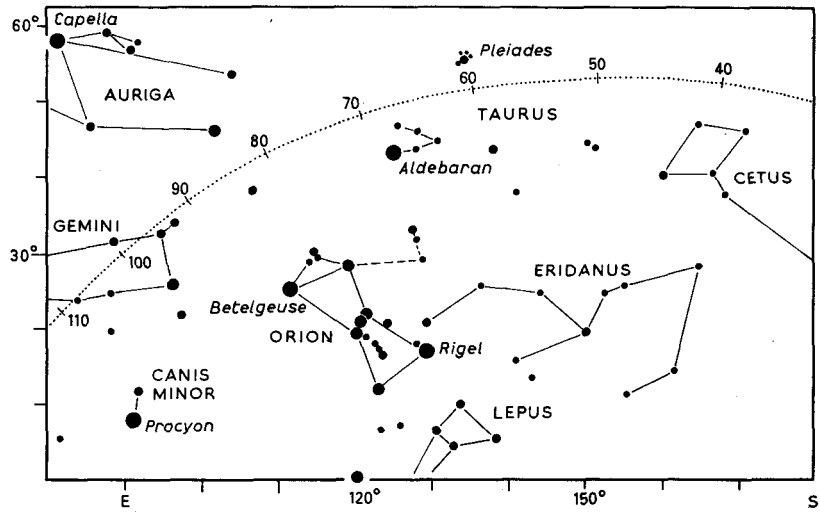
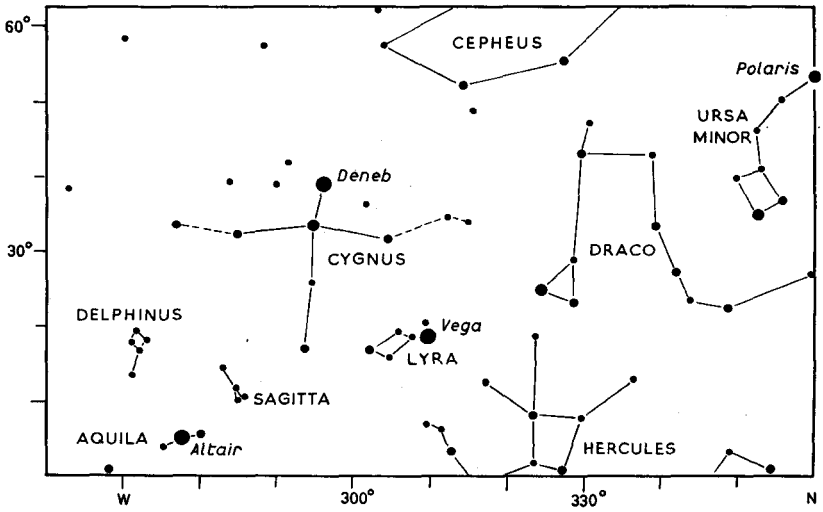
December 6 at 21h	December 21 at 20h
January 6 at 19h	January 21 at 18h





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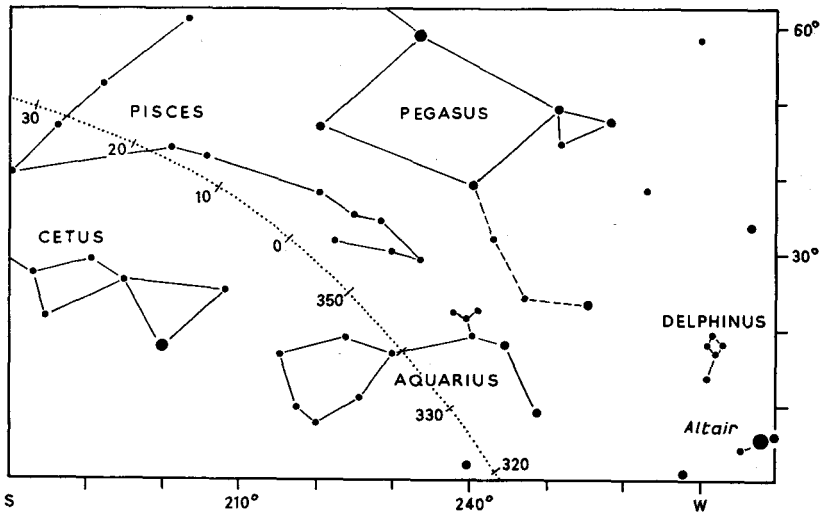
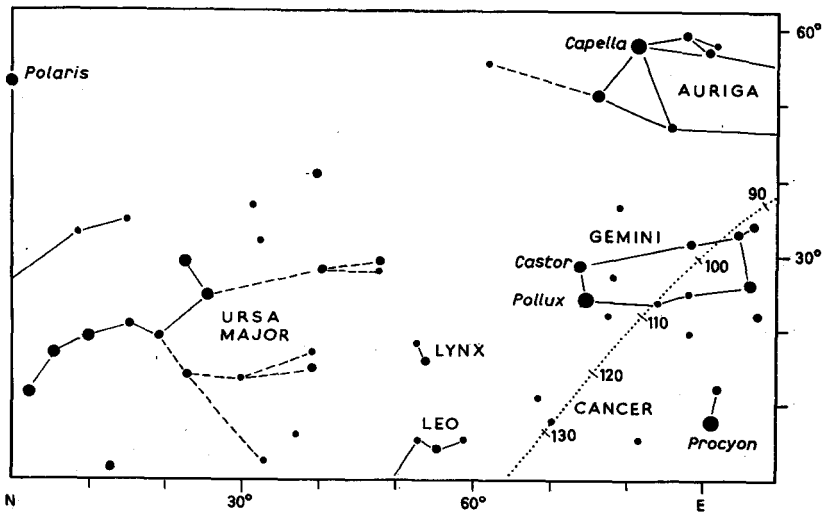
December 6 at 21h	December 21 at 20h
January 6 at 19h	January 21 at 18h

11R





12L

October 6 at 3h	October 21 at 2h
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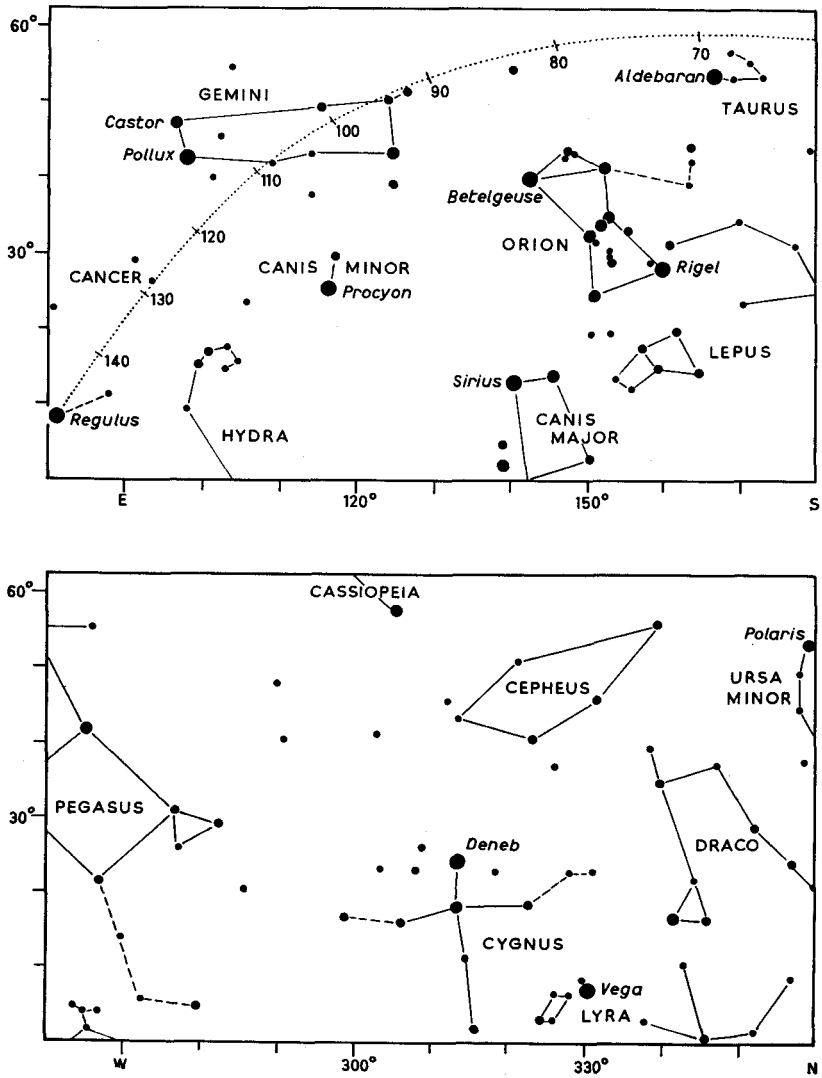
January 6 at 21h	January 21 at 20h
February 6 at 19h	February 21 at 18h



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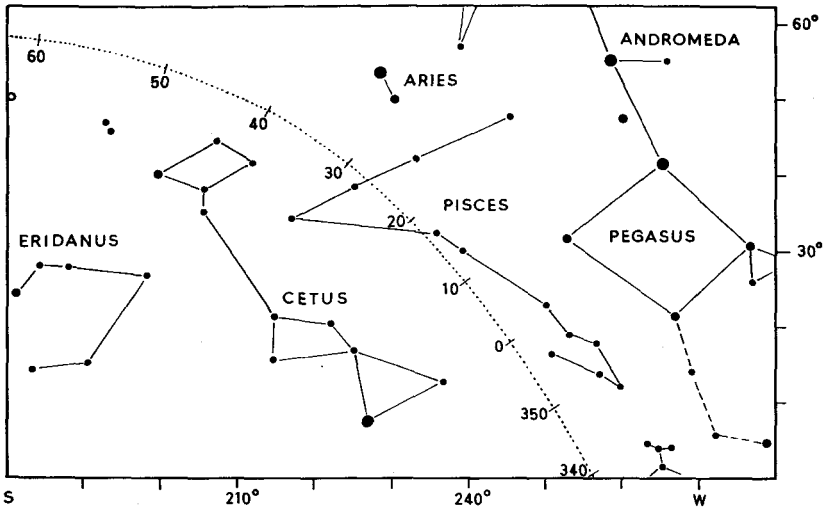
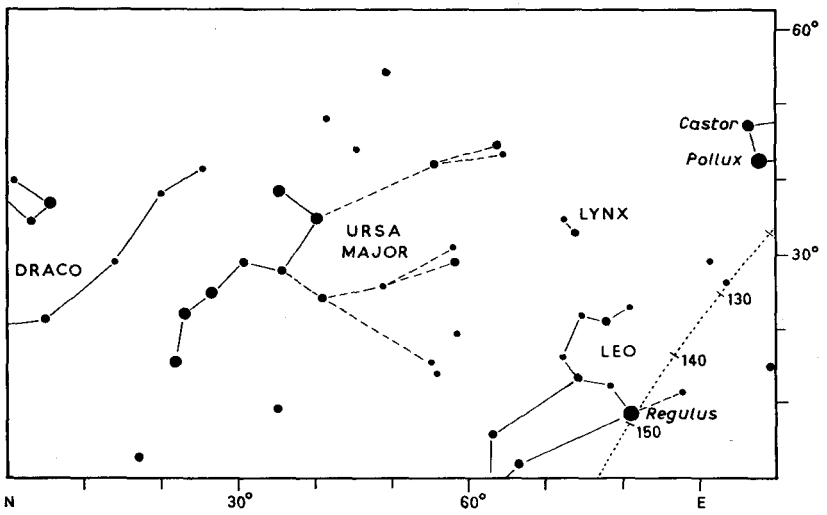
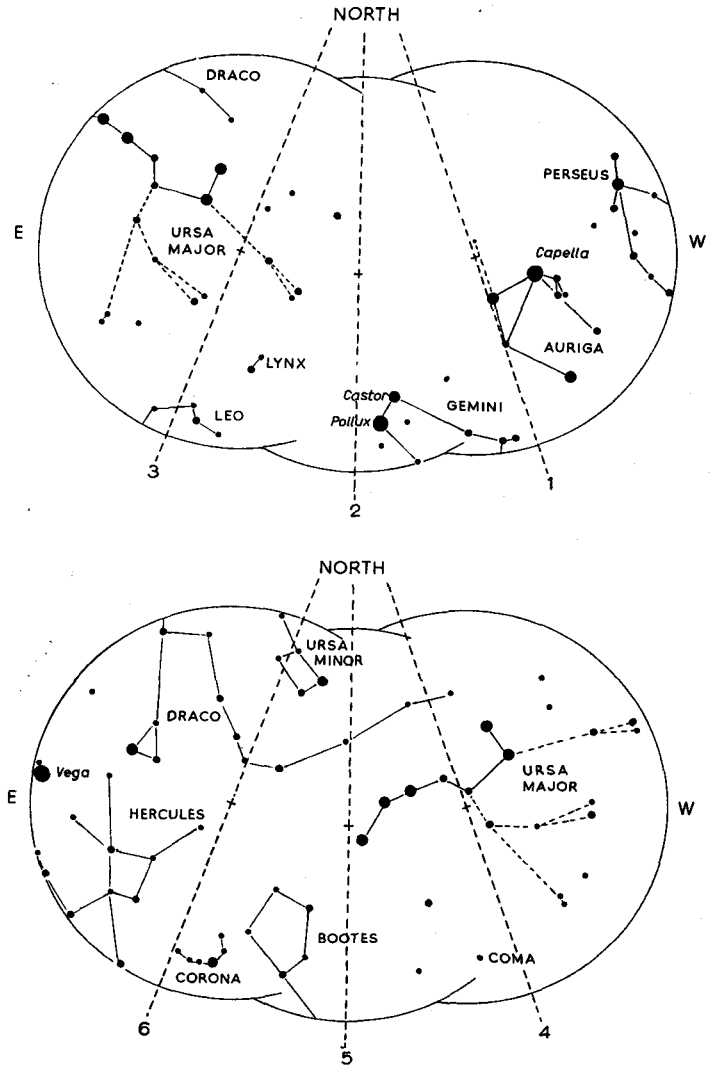
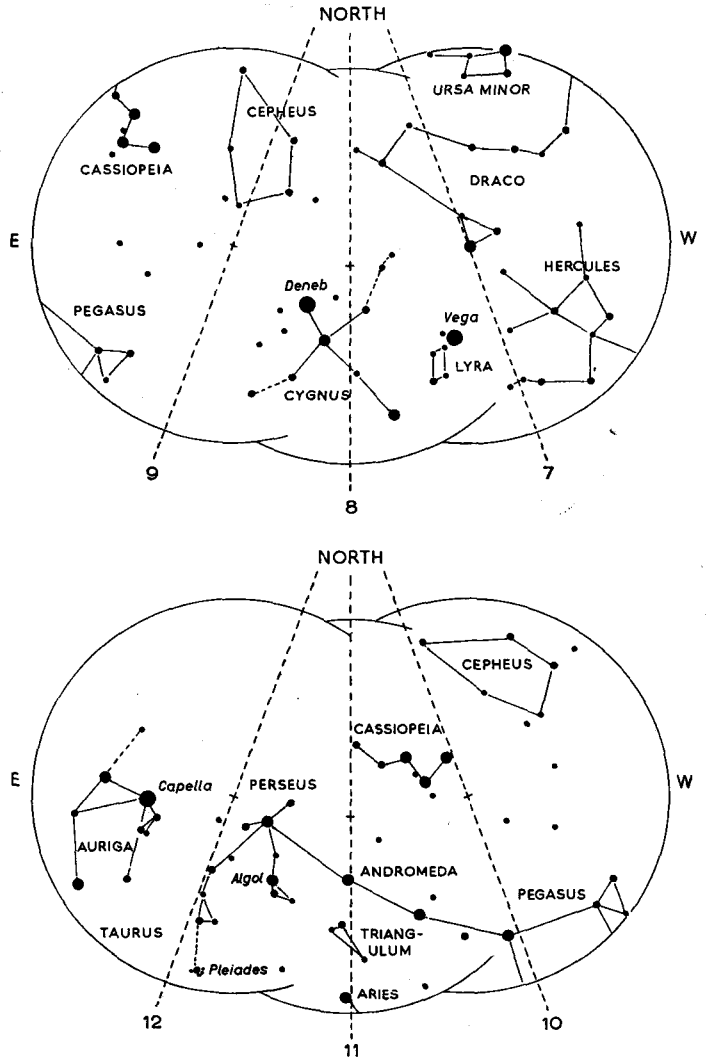
February 6 at 19h	February 21 at 18h	







Overhead stars



Overhead stars

Eclipses, 1962

There are only two eclipses in 1962, and as this is the minimum number possible, they are both eclipses of the Sun. Neither of them will be visible in this country.

1. *A total eclipse of the Sun* will occur on February 4–5; the path of totality begins in Borneo and crosses New Guinea and the Solomon Islands, ending in the Pacific Ocean near the western coast of Central America. The maximum duration of the eclipse is 248 seconds. A partial eclipse of the Sun will be seen over a large area of the Pacific Ocean, and in Australia.
2. *An annular eclipse of the Sun* on July 31 will be visible from a narrow track beginning in Venezuela, and crossing the Atlantic to West Africa, Nigeria and Tanganyika, ending at the northern end of Madagascar. The maximum duration of the annular phase will be 213 seconds. A partial eclipse will be seen from most of Central and South America, Spain and the whole of Africa.

Penumbral eclipses of the Moon are not obvious to the naked eye as the change in the light of the Moon is very small. There are three such eclipses in 1962, at the Full Moons of February 19, July 17, and August 15; only part of the last of these is visible in this country.

Occultations

In the course of its journey round the sky each month, the Moon passes in front of all the stars in its path, and the timing of these occultations is useful in fixing the position and motion of the

Moon. The Moon's orbit is tilted at more than 5 degrees to the ecliptic, but it is not fixed in space. It twists steadily westwards at the rate of about 20 degrees a year, a complete revolution taking 18·6 years, during which time all the stars that lie within about $6\frac{1}{2}$ degrees of the ecliptic will be occulted. The occultations of any one star continue month after month until the Moon's path has twisted away from the star, but only a few of these occulations will be visible at any one place in hours of darkness.

These facts are illustrated in 1962 by occultations of the bright stars *Regulus* and *Aldebaran*. *Regulus* is very close to the ecliptic, and at the present time, the Moon's orbit is so placed that it crosses the ecliptic from south to north very near the place of *Regulus*, and the star is occulted each month. The series of occultations began in January 1961 and will end in May 1962; only one favourable case, on April 14, is described in the monthly notes. In nine years' time, the Moon's orbit will have twisted round so that the Moon passes from north to south near *Regulus*, and another series of occultations of this star will begin.

The star *Aldebaran*, on the other hand, is more than 5 degrees south of the ecliptic, so that it is far from the nodes, where the Moon crosses the ecliptic. It can therefore only be occulted by the Moon in the most southerly part of its orbit, and in this case there is only one series of occultations. The present series began in July 1959, and will end in September 1962. The occultation of *Aldebaran* on February 12 should be well seen in this country, and is described in the monthly notes.

Most of the planets are occulted during 1962, but only two of these phenomena are visible here. On March 4, Mercury is occulted during the hours of daylight, but a more interesting event is the occultation of Saturn on the night of November 4, when the Moon at First Quarter will occult the planet as seen from southern England. Details of all the planetary occultations, and of all stars down to magnitude 7·5 are published in the *Handbook* of the British Astronomical Association.

Comets in 1962

It is seldom safe to make predictions about the appearances of comets, since it is always possible for a really bright one to turn up unexpectedly. However, some of the periodic comets may be expected during the year, but these are all faint objects, beyond the reach of small instruments. They are detected by photography, using large telescopes, and a great deal of this work is done by Dr Elizabeth Roemer, using the 40-inch reflector at the Flagstaff (Arizona) Station of the U.S. Naval Observatory. In 1960 Miss Roemer had no less than twenty-three comets under observation, seven of which were periodic comets which she had herself recovered. Some of the periodic comets which are due to return in 1962 are old friends, and all of them have some point of interest.

Comet Tempel (*2*), first seen in 1873, has made twelve previous appearances. It has a period of 5·3 years, and has already been recovered by Miss Roemer (in March 1961) although it is not due at perihelion until May 1962.

Comet Faye has a longer period (7·4 years) and is expected to return to perihelion in May 1962. It was first seen in 1843, and has made fourteen previous returns.

Comet Perrine-Mrkos was discovered by Perrine in 1896 and seen again in 1909. It was then lost, and had been abandoned by most computers, but was recovered in 1955 by Antonín Mrkos. The comet has a period of about 6·5 years, and should return to the Sun in February 1962.

Comet Tuttle-Giacobini-Kresák has had a curious history. It was seen for only thirty-one days in 1858, and for eleven days in 1907, and in spite of much laborious work, it was found impossible to deduce a reliable orbit. It was not until April 1951, when Kresák discovered the comet again, that it was realized that there had been nine revolutions between 1858 and 1907, and eight between 1907 and 1951. A good orbit is now available, and the comet should return in March 1962.

Comet Neujmin (*3*) was seen in 1929 and 1951, but was missed

in 1940. It has a period of nearly eleven years, and is predicted to return in April 1962.

Comet Harrington-Abell, which has a period of 7·2 years, has only been seen once before – in 1954. It should return in March 1962, when observations should provide a more reliable orbit.

Comets Schwassmann-Wachmann (1) and *Oterma* are visible every year because they travel round the Sun in orbits which are much more nearly circular than those of most other comets. Comet Schwassmann-Wachmann has an orbit with a period of sixteen years which lies entirely between the orbits of Jupiter and Saturn. It undergoes remarkable changes of brightness, which seem to have some connexion with solar activity. Comet Oterma has a smaller orbit, lying between those of Mars and Jupiter, and resembling the orbits of certain minor planets. The period at present is nearly eight years, but Miss L. Oterma has shown that the comet will make a close approach to Jupiter in 1962–64, and this will cause the orbit to become much larger and more eccentric, with a period of nineteen years. As a result the comet will only be visible in large telescopes after 1962, because its perihelion distance will have increased from 3·4 to 5·3 astronomical units.

Meteors

Meteors ('shooting stars') may be seen on any clear moonless night, but on certain nights of the year their number increases noticeably. This occurs when the Earth chances to intersect the orbit of a meteor swarm, which is a concentration of meteoric dust moving in an orbit around the Sun. Such an intersection can occur only at one particular time of year, but if the dust is spread out along the orbit, the resulting shower of meteors may last for several days. The word 'shower' must not be misinterpreted—only on very rare occasions have the meteors fallen so fast as to resemble snowflakes falling.

The naked-eye study of meteors is quite a laborious task, but

even a casual observer, watching for, say, ten minutes on an August night, may observe a number of Perseids. If their tracks are marked on a star map, and traced backwards, a number of them will be found to intersect in a point (or a small area of the sky) which marks the radiant of the shower. This gives the direction from which the meteors have come.

The following table gives some of the more easily observed showers, with their radiants; the effect of moonlight in 1962 is indicated.

Limiting dates	*Shower*	*Maximum*	*R.A.*	*Dec.*	*Notes*
Jan. 3–4	Quadrantids	Jan. 3	$15^h\ 28^m$	$+50°$	D
April 20–22	Lyrids	April 22	$18^h\ 04^m$	$+33°$	M
July 27–Aug. 17	Perseids	Aug. 12	$3^h\ 04^m$	$+58°$	M
Oct. 15–25	Orionids	Oct. 20–21	$6^h\ 24^m$	$+15°$	
Oct. 26–Nov. 16	Taurids	Nov. 1–7	$3^h\ 36^m$	$+14°$	
Nov. 15–17	Leonids	Nov. 16	$10^h\ 08^m$	$+22°$	
Dec. 9–14	Geminids	Dec. 13	$7^h\ 28^m$	$+32°$	M
Dec. 20–22	Ursids	Dec. 22	$14^h\ 28^m$	$+76°$	

D=maximum of shower in daylight
M=moonlight interferes

Minor Planets in 1962

Of the 1,600 minor planets which are listed in the catalogues, only the "big four", Ceres, Pallas, Juno and Vesta, can reach any considerable brightness, and only the last of these, Vesta, can occasionally be seen with the naked eye. In 1962, however, Vesta only rises to magnitude 6·9 at the end of the year. Ceres will also reach the same magnitude, while Pallas will be a little fainter at 7·0, and Juno does not rise above 8·6.

The minor planets can depart very considerably from the ecliptic, owing to the greater inclinations of their orbits. Thus it is interesting to note that at the end of 1962, Ceres, Juno and Vesta are all in the same part of the sky at the eastern end of Leo, but while Ceres has a declination of 17 degrees north of the equator, Vesta is only about 8 degrees north, and Juno is 2 degrees south of it.

Some Events of 1963

ECLIPSES

In 1963 there will be four eclipses, two of the Sun and two of the Moon; there will also be a penumbral eclipse of the Moon.

Jan. 25 – an annular eclipse of the Sun, visible in the South Atlantic.

July 6 – a partial eclipse of the Moon; 71 per cent of the Moon will be covered with the Earth's shadow, and the event will be visible from this country.

July 20 – a total eclipse of the Sun, visible in eastern Asia, Alaska and Canada.

Dec. 30 – a total eclipse of the Moon, not visible in this country.

The penumbral eclipse of the Moon occurs on January 9.

THE PLANETS

Mercury will be seen to best advantage as an evening star at greatest eastern elongation on April 26, and as a morning star at western elongation on October 5.

Venus will be a morning star until August. Greatest western elongation occurs on January 23, superior conjunction on August 30.

Mars will be at opposition on February 4, on the borders of Cancer and Leo; distance 62 million miles. It will be an evening star for the remainder of the year.

Jupiter is in conjunction on March 16, and at opposition on October 8, when it will be in the constellation Pisces.

Saturn is in conjunction on February 3, and at opposition on August 13, still in Capricornus.

Uranus will be at opposition on February 22 and *Pluto* on March 2, both planets being still in Leo; *Neptune* comes to opposition on May 5 in Libra.

The minor planet *Vesta* will reach magnitude 6 when in opposition in March among the stars of Virgo.

The Structure of the Galaxy

R. H. GARSTANG

The nature of the Milky Way has always been a subject for discussion among astronomers. Galileo was the first to show that the Milky Way consisted of stars. Many years later, Wright speculated on its disk form, and Kant suggested that other hazy celestial objects were similar in nature to the Milky Way. The Earl of Rosse discovered the spiral structure of many of the nebulæ, and the possibility became apparent that our own Milky Way was a galaxy, perhaps with a spiral structure.

This possibility was strengthened by the first observations of the spectrum of the Andromeda Nebula, which proved that the Nebula consisted in the main of stars. Progress in the study of our own Galaxy was slow, not least because our position inside the Galaxy makes it almost impossible to attempt to perform observations on any part of the system other than our own immediate neighbourhood. This is because matter which exists in interstellar space absorbs the light from the distant stars in our own Galaxy, and prevents us from seeing such stars. From the time of Herschel much attention had been devoted to attempts to determine the size and shape of the Galaxy from star-counts, but the later discovery of interstellar absorption rendered much of this early work of little permanent value. It did, however, suffice to show that our Galaxy had a much greater diameter than thickness.

On the basis of this early work it seemed as though the Sun were near the centre of the Galaxy, but this idea later proved to be incorrect. Shapley studied the distribution of the globular clusters, and demonstrated beyond doubt the eccentric position of the Sun in the Galaxy. The Cepheid variable stars which globular clusters

contain have known absolute brightnesses, and this enabled the distances of the globular clusters themselves to be obtained, leading to a determination of the size of the Galaxy and the distance from the Sun to the galactic centre. Shapley's observations were largely made away from the plane of the Galaxy, and so avoided the worst effects of interstellar absorption. His results were correct in principle, although his numerical data have subsequently been revised.

It was realized that interstellar absorption would lead to large uncertainties in the estimates of the size of the Galaxy, but it was not until the work of Trumpler in 1930 that the existence of interstellar absorption was finally proved. Trumpler studied galactic star-clusters, small groups of perhaps one or two hundred stars which are found fairly close to the Milky Way. He estimated the distances of the clusters from the brightnesses and spectral types of the stars which they contain, and their diameters from their apparent angular diameters and distances. He found that the more distant clusters were – apparently – systematically larger than the nearer clusters. This was very improbable on general grounds, and Trumpler inferred that the distances must be erroneous. If interstellar absorption were present, the distances of remote clusters would be under-estimated. Trumpler assumed that all clusters of a given type were comparable in size, and he calculated what interstellar absorption would be needed to give the observed apparent distances. He found that the absorption in visual light was about 0·1 magnitude for every 1,000 light-years of distance, and about double this for photographic observations in blue light. This absorption is concentrated close to the Milky Way plane, mostly within a distance of 500 light-years to either side of the plane, and for this reason it did not interfere too seriously with Shapley's work.

Many other lines of evidence supported the idea that our Galaxy must be a large aggregate of stars, with the Sun as one of these stars and situated at some distance from the centre of the aggregate. There were some difficulties, most of which later disappeared as our knowledge increased. For example, it was long

believed that our Galaxy was very much larger than the Andromeda Nebula, and it was consequently argued that one should not expect the two to be closely similar in other respects. But the early estimates of Shapley, and others, of the size of our Galaxy proved to be too great by a factor of two. Furthermore, as better instruments became available to astronomers, faint extensions of the Andromeda Nebula were discovered, showing that it is larger than had been thought. Finally, in 1952, Baade showed that the distance of the Andromeda Nebula had been under-estimated, and that it should be approximately doubled. The net effect of all this work was to make the Andromeda Nebula a little larger than our Galaxy on the best available estimate, so that the difficulty about the relative sizes of the two galaxies disappeared.

The Galactic Plane and Poles

There have been many determinations of the plane of the Milky Way and the poles of the Galaxy. These may be determined by studying distant stars, and finding the best small circle which passes through the distribution of these distant stars on the celestial sphere – or by some similar method. Distant supergiants, variable stars, star-clusters, planetary nebulæ and other objects have been used for this purpose. More recently, radio astronomy has provided a still better method, by enabling us to determine the mean plane of the interstellar hydrogen gas which is present in and near the galactic plane. This hydrogen gas emits radio waves, and these can be received and measured. It has been shown that this layer of hydrogen gas is remarkably flat over a large part of the galactic plane (though in the outer parts of the Galaxy there are some deviations from this plane), and serves to give a good definition of the galactic plane itself. Interstellar gas also gives a continuous radio radiation, and observations of this confirm the results from the hydrogen line radiation. The radio results are probably better than the optical ones, because the radiation comes from a much larger region of the Galaxy and so is more representative of the whole. Moreover, the radio data are not affected by observational selection as seriously as are optical data. The finally

adopted position of the north galactic pole is: R.A. $12^h\ 49^m$, Dec. $+27°{\cdot}4$ [1950·0]. The Sun is situated in the plane of the Milky Way, to the accuracy of present observations; such results as exist suggest that the Sun may perhaps be a few tens of light-years north of the plane.

The Galactic Centre

The direction of the centre of the Galaxy has been determined optically by studying the distribution of distant objects – stars, planetary nebulæ, variable stars and globular clusters – and finding the direction of the maximum frequency of occurrence. It has been determined from radio-astronomical observations of both continuous emission and of line emission from interstellar hydrogen. The final result is that the centre lies in direction: R.A. $17^h\ 42^m{\cdot}4$, Dec. $-28°\ 55'$ [1950·0]. The distance of the centre has been determined from variable stars. Counts are made of the number of variable stars of different apparent magnitudes in directions as near to that of the centre as possible (but avoiding the worst of the interstellar absorption), and the distance of maximum frequency of occurrence in approximately that of the centre. Estimates have also been made from the distribution of globular clusters, and by methods depending on the theory of the rotation of the Galaxy. The value adopted for the distance of the centre is 26,800 light-years; the latest indications are that a slightly larger value would be better.

Galactic Rotation

In 1928, Oort showed that the Galaxy is rotating about its centre. The rotation is not uniform; the angular velocity is greatest near the centre, and diminishes outwards. To a first approximation the individual stars are treated as moving in circular orbits around the centre. They have small velocities relative to these circular motions because the orbits are not perfectly circular, but have finite eccentricities and are inclined at (usually) small angles to the galactic plane. Owing to the non-uniform angular rotation, stars which are more distant from the centre than the Sun are moving

more slowly round the Galaxy, and observations of the velocities of the stars from the Sun – actually, observations are made on the Earth and the velocities as seen from the Sun are calculated – can be used to determine the differential rotation between stars and the Sun. The proper motions of the stars are also affected by galactic rotation, and from the two sets of observations the angular velocity of the Galaxy in the neighbourhood of the Sun can be calculated. The period of revolution is 240 million years; assuming that the Sun is 26,800 light-years from the galactic centre, the speed of the Sun in its orbit round in the Galaxy is 210 km. per second.

Mass of the Galaxy

The mass of the Galaxy must be inferred from other known properties. Using data on galactic rotation, distance of the centre from the Sun, star-counts and other information, models are set up, composed of a superposed series of spheroids of various densities, shapes and sizes. The spheroids are adjusted so that the properties of the model agree as closely as possible with the properties of the real Galaxy, and the mass of the model then gives the best available estimate of the mass of the Galaxy. It turns out that most of the mass of the Galaxy is in its central regions. The total mass is estimated to be $0{\cdot}70 \times 10^{11}$ times the solar mass.

Distribution of Stars perpendicular to the Galactic Plane

All stars show some degree of concentration toward the galactic plane, but some to a greater degree than others. Stars of types O and B and classical Cepheid variables are very concentrated to the plane, most of them lying within 500 light-years on either side of it. At the other extreme, cluster-Cepheids, globular clusters and the planetary nebulæ are much less concentrated to the plane, many of them being found at distances up to 20,000 light-years or more from it. The different types of stars are often considered as forming sub-systems; the O and B stars are part of the flat sub-system, the cluster-Cepheids part of the spherical sub-system. These sub-systems are closely related to the 'populations' of stars as discussed by Baade.

Spiral Structure of the Galaxy

Observations of extragalactic nebulæ had suggested that our Galaxy is a spiral nebula, but the detection of spiral arms proved to be difficult. Attempts to detect arms by looking for maxima in the stellar distributions were not successful. It became clear that success would be possible only if objects could be found which marked out spiral arms more clearly than most normal stars. Baade showed that large glowing clouds of gas, supergiant stars of types O and B, and galactic star-clusters in the Andromeda Nebula all outlined the spiral arms of the Nebula. In 1951, Morgan and his colleagues determined the distances of many luminous hydrogen gas-clouds in our Galaxy, plotted them out and showed that they outlined portions of three spiral arms. One passed very close to the Sun; indeed, the Sun could be regarded as being near its inner edge. A second arm was situated some 8,000 light-years further from the galactic centre than the Sun; the third arm was some 6,000 light-years nearer to the centre.

A number of more recent studies confirm this general picture, and add more detail. The study of interstellar absorption lines is one important technique. In addition to the effect of interstellar matter in dimming the light of the distant stars, interstellar gas produces absorption lines in the spectra of the stars. These lines are very sharp, and are often resolved into several very close components. The exact position of each component of a line can be determined. The components are slightly shifted from their normal positions because of Doppler effects arising in the interstellar gas clouds in which the absorption components are formed. If use is made of information on galactic rotation, the location of the gas-clouds can be determined. Nearby stars contain one main absorption component, and this has been shown to arise in the spiral arm of the Galaxy nearest to the Sun. Many of the more distant stars show one or more components which arise in the outer spiral arm. The information obtained in this way agrees with the picture of the spiral arms obtained by Morgan.

Galactic radio astronomy

As mentioned earlier, interstellar hydrogen gas emits radio waves in the form of a spectrum line. This situation is very unusual in radio astronomy; most objects emit only a continuous spectrum. Hydrogen atoms emit radiation of wave-length 21 cm. Very large volumes of gas are needed to give an appreciable amount of radiation, and the study of this radiation is an excellent method of obtaining information on the large-scale structure of the Galaxy. Radiation from interstellar hydrogen on 21 cm. wave-length was first detected in 1951 by American, Dutch and Australian radio astronomers simultaneously and independently. The observations give a 'profile' of the hydrogen line. This profile often shows several peaks, each of which can be interpreted as emission by a different large interstellar gas-cloud. Because of Doppler effects, the lines emitted by different clouds do not coincide, but are very slightly shifted in wave-length. Frequently these shifts can be used to locate the clouds in the Galaxy. When this is done, it is found that the clouds of hydrogen gas agree closely in location with the spiral arms of the Galaxy as determined optically. It should be pointed out that the radio emission arises from neutral hydrogen, whereas the optical radiation arises from ionized hydrogen regions.

Very little hydrogen is found beyond 50,000 light-years from the galactic centre. Some curious results have been obtained from the region near the centre itself, however. It appears that much of the hydrogen in this region is expanding outwards with velocities of up to 100 km. per second. Measures of the intensities of the hydrogen radiation have shown that the temperature of the interstellar gas is about 120 degrees absolute (−230° F.) and the density of hydrogen is 1 to 3 atoms per cubic centimetre in the spiral arms, though less than 0·1 atom per cubic centimetre between the arms.

Some continuous radio radiation is received from the Galaxy. Part of this arises from individual radio sources, such as the Crab Nebula and other supernova remnants. There is, however, an appreciable contribution which arises from the corona (or halo)

of the Galaxy. This was discovered because of the low ratio of radio emission between directions in the plane and toward the galactic poles. More radiation is received from the direction of the galactic poles than had been expected. It seems as if the Galaxy possesses a very large and very tenuous halo of hydrogen gas (no doubt there will be a few stars as well; some faint blue stars are known which are probably members of the halo). Its density is probably 1/1000 of that in the spiral arms. There are probably some free electrons, and a weak magnetic field; and it is the motion of these which produces the radio radiation.

Magnetic Fields in Spiral Arms

It has been suggested that magnetic fields are present in the spiral arms. Light from distant stars in the Milky Way is polarized. The polarization is probably produced by clouds of magnetized particles in interstellar space. Such particles must show a preferential alignment in space if they are to produce polarization. Large-scale magnetic fields seem to be the only agency capable of lining up magnetic particles. The magnetic fields seem to stretch along the spiral arms, but what happens to the fields at the ends of the arms is not known; possibly the lines of force link up by passing through the galactic halo and into the nucleus. Another reason for believing that magnetic fields are present in the spiral arms is because of the need for stabilizing the spiral arms. It is hard to see, on dynamical grounds alone, how the long thin spiral arms could remain stable against the shearing effects of galactic rotation. It is possible to calculate the magnetic field needed to line up interstellar magnetic particles and the field needed to maintain stability in the spiral arms, and the two independent estimates agree at a field of 10^{-5} gauss.

Stellar Populations and Evolution

The concept of stellar populations was introduced in 1944, by Baade, to describe his observations of extragalactic nebulæ. The nuclei of spiral nebulæ and elliptical nebulæ were Population II; the arms of spiral nebulæ were Population I. Both populations

occur in our own Galaxy in our neighbourhood, and presumably in other parts of the Galaxy. Recent work has led to some modification of Baade's ideas, in that Morgan and Mayall have shown that there must be very many Population I stars in the nucleus of the Andromeda Nebula, as well as the Population II stars discovered by Baade. Giant elliptical nebulæ seem to contain certain types of Population I stars, those which are believed to be older, while the small elliptical nebulæ probably contain only Population II stars. This has been interpreted in terms of an evolutionary theory. All galaxies are supposed to have been formed at about the same time, but star formation proceeds at different rates in different nebulæ. In the small elliptical nebulæ, all the stars were formed long ago, and none have subsequently been formed. In large elliptical nebulæ star formation continued up to a more recent epoch, and then stopped. In the arms of spiral nebulæ, star formation is still in progress. This is consistent with other observations, for only when interstellar matter is present can stars be formed, and such matter is very abundant in spiral arms. These theories are not accepted in their entirety by all astronomers, but there is agreement that in spiral galaxies in general, and in our Galaxy in particular, star formation is still in progress in the spiral arms. Of the evolution of the spiral arms very little is known, and their evolutionary history remains one of the major puzzles of astronomy.

Radio and Radar Astronomy

R. C. JENNISON

The Origin of Radio Astronomy

Radio Astronomy, the science of detecting and analysing the radiations from the cosmos at radio frequencies, had its origins in the work of Karl Jansky, an American radio engineer who, in the course of investigating atmospherics in the early 1930s, observed that the atmospherics contained a continuous component, a background hiss, which always reached a maximum when he pointed his aerial at the Milky Way in Sagitarrius.

The work remained a scientific curiosity until Reber, an American radio amateur, constructed his own radio telescope and between 1938 and 1940 produced the first maps or *isophotes* showing the distribution of radiation over the celestial sphere. The interest aroused by Reber's work, and the advances in technique attained during the war, resulted in a number of important discoveries in the immediate post-war years. The various branches of radio astronomy listed below were all firmly established within a dozen years of Reber's first published survey.

The Galaxy

The whole plane of the Milky Way radiates strongly over the short-wave band. This was the radiation first detected by Jansky, and it contributes considerably to the noise heard in a good short wave or television receiver. The radiation is spread over the whole of the Milky Way but is most concentrated in the direction of the galactic centre in Sagittarius. Here and there distinct patches stand out from the background of radiation, and these are usually listed as individual sources. Strongest amongst these are the sources in Cassiopeia and Taurus. The radio source Cygnus A also lies in

TABLE I

The Most Intense Radio Sources

Source	*Position (1950)*		*Photo Mag.*	*Size and Shape*		*Distance** (*light-years*)	*Description*
	R.A.	*Dec.*		*Optical*	*Radio*		
Galactic							
Taurus A	$05^h\ 31^m{\cdot}5$	$+21°\ 59'$	9·0	$4' \times 6'$	$4'$	4×10^3	Type I supernova remnant
Cassiopeia A	$23^h\ 21^m{\cdot}2$	$+58°\ 32'$	complex	$4'{\cdot}1$ disc with spur	$4'{\cdot}1$ disc with spur	10^4	Type II supernova remnant
Extragalactic							
Virgo A	$12^h\ 28^m{\cdot}3$	$+12°\ 40'$	9·9	$3' \times 3'$	$5'$	4×10^7	Galaxy with jet
Centaurus A	$13^h\ 22^m{\cdot}4$	$-42°\ 45'$	6·1	$10' \times 8'$	$3' \times 6'$ doublet with double nucleus	10^7	Galaxy with dark band
Cygnus A	$19^h\ 57^m{\cdot}75$	$-40°\ 36'$	17·1	$0'{\cdot}3 \times 0'{\cdot}5$	$2' \times 0'{\cdot}5$ doublet	$5{\cdot}5 \times 10^8$	Colliding galaxies

The source Sagittarius A is not listed above as it is a complex distribution of thermal and non-thermal components. It has a right ascension of $17^h\ 43^m{\cdot}1$ and declination $-20°\ 59'$. It may be in part associated with the nucleus of the Galaxy.

* Assuming a value of Hubble's constant 100 km/sec/kiloparsec.

the direction of the galactic plane, but its presence there is purely fortuitous as it is an extremely distant object, far beyond our own Galaxy. Apart from the coincidence of the overall position of the Milky Way with the general distribution of radio brightness from the Galaxy, there is very little detailed correlation in its appearance at optical and radio frequencies. This is principally due to the fact that the radio waves can penetrate, unmolested, through the dust clouds that obscure the optical features at very short distances. This is why the centre of the Galaxy is so bright at radio wave-lengths but is completely obscured in the optical region.

The very strong radiation from the Galaxy appears to originate in the integrated radiation from myriads of cosmic rays particles which each radiate a very small amount of radio frequency energy as they dash about at speeds approaching that of light. These particles probably originate in the remnants of exploded stars such as the supernovae which are identified as individual radio sources. Where the remnants have become dispersed over long periods of time, the radiation from such parts, superimposed on similar radiation from greater distances, gives rise to a general distribution of radiation in the galactic plane. There is, in addition, a 'thermal' component of radiation from the galactic disk which is detectable at very high frequencies.

Away from the Milky Way, at large angles from the disk of the Galaxy, strong radiation is still detected at low frequencies. This radiation cannot be resolved into detailed structure and appears to emanate from a spherical region surrounding the whole galaxy. This is a similar distribution to that found for the globular clusters of stars and forms the halo or corona of the Galaxy. Again the source of radiation appears to be cosmic ray particles associated with a general magnetic field of the Galaxy.

The spectrum of the radiation from the Galaxy is continuous, but it slopes down from the longer to the shorter wave-lengths so that the flux received on a unit area of the Earth's surface is approximately proportional to the wave-length raised to the power 0·6. This spectrum is superimposed on the fainter flat spectrum from the disk.

A further contribution to the radiation from the Galaxy has provided one of the most valuable tools for investigating its structure. This is the spectral line of hydrogen at a wave-length of 21 cm. It will be discussed separately under that heading.

Radio Stars

The name 'radio star' is a misnomer, and originates from the discovery of localized intense sources of radiation superimposed upon the general background of radiation from the Galaxy. At first these sources could not be resolved by the radio telescopes then in use and so appeared to behave as point sources, just as stars do when viewed with an optical telescope. Furthermore all attempts to identify the sources with optical objects were at first doomed to failure, and a possible hypothesis was that each radio star was some form of dark stellar body.

The first radio star to be identified was the source Taurus A. This was found to coincide with the Crab Nebula, which, far from being stellar, is a tenuous, highly excited nebula a few light-years across. This nebula coincides with the position where, in the year 1054, the Chinese astrologers recorded seeing a brilliant guest-star flare into life and die again into insignificance. The present rate of expansion of the nebula shows that it must have originated in the same year and it is clear that what we now see is the remnant of a supernova.

The most intense of all the radio sources, Cassiopeia A and Cygnus A, were not identified for a number of years, despite intensive efforts by a number of observatories. Eventually, accurate positions, backed up by measurements of the diameter of the source of radio wave-lengths, enabled Cassiopeia A to be identified with a remarkable new type of nebulosity, very faint and tenuous, but showing a very high degree of excitation. It is now thought to be the remnant of a supernova situated in our own Galaxy. The picture of Cassiopeia A that can be built up by analysis of the readings obtained with radio interferometers is almost an exact reproduction of the picture obtained with very long exposures with the 200-inch optical telescope.

The identification of the second strongest radio source, Cygnus A, has had a remarkable effect upon the current interests in astrophysics and cosmology. Cygnus A was identified, from photographs taken with the 200-inch Hale telescope, with an 18th magnitude extragalactic object at a distance of over five hundred million light-years. This curious object, in which a great part of the light is from emission lines and which produces an equal amount of energy in the radio frequency spectrum, is interpreted as the collision of two entire galactic systems. In such a collision few stars are likely to collide, but the gas, dust and magnetic fields experience the full force of a collision at thousands of kilometres per second. In optical appearance, Cygnus A is a hazy object measuring about 18 by 30 seconds of arc overall, with two bright nuclei in the centre. At radio wave-lengths it appears as a very much larger object, with two great blobs separated by nearly 1·5 minutes of arc between their centres; and there is little or no radiation from the central region where the optical source is situated.

Recent surveys with large radio telescopes, such as the interferometer systems at the Mullard Radio Astronomy Observatory of Cambridge University and the Mills Cross aerial of C.S.I.R.O. in Australia, show that there are well over a thousand radio 'stars', the vast majority of which are extragalactic objects. Up to the time of writing, the most distant of these objects to be identified is also the most distant object yet detected in the universe. This is the source I.A.U. 14N5A in Boötes, which was identified at the 200-inch telescope with a very faint nebula having an emission line spectrum. The spectrum was shifted to the red to such an extent that the lines normally in the ultra-violet appeared in the green part of the spectrum. Measurement of the red shift on these lines shows that the nebula is receding at 46 per cent of the speed of light, which corresponds to a distance of 6,000 million light-years.

Current research into the subject of radio stars is largely concentrated on more detailed and accurate surveys in order to endeavour to establish the law relating the number of sources to

their intensities. From simple considerations of the volume of a sphere and the inverse square law for the decrease of intensity with distance, it is possible to show that, if the universe is evenly populated with sources of the same intrinsic brightness, the number detected with an intensity greater than any value I will be proportional to $I^{-3/2}$. The same result would hold if a population of stars of different intrinsic brightness had been chosen; indeed, most brightness distributions for the sources yield a similar result for the number observed with an apparent brightness greater than any chosen value.

The 'three-halves power law' referred to in the previous paragraph assumes that the universe is static and Euclidean. In such a universe we should expect statistical fluctuations in any region of space to produce a small random scatter in the source counts; but a diagram in which the logarithm of the number of sources exceeding a certain flux density is plotted against the logarithm of that flux density should show a distribution of points closely defining a straight line with a slope of $-3/2$. If, however, the universe is not in a steady state, departures from the law may be expected; in particular the model of a universe expanding from the explosion of a primeval atom would lead us to expect that the sources in the far distance would be more densely packed, because they are seen as they were when the radio waves left them, thousands of millions of years ago, in an epoch when all the galaxies were packed into a smaller space. A universe of this type would result in a deviation from the 'three-halves power law' which would cause its slope to be steeper, for there would be more faint sources in proportion to the nearer and stronger ones. Such a deviation has been deduced by Martin Ryle and his colleagues at the Mullard Radio Astronomy Observatory, Cambridge. They find that the slope of the curve is about $-1{\cdot}8$, which appears to be a significant deviation from the value of $-1{\cdot}5$ given by the $-3/2$ law, which would hold if the simple concept of continuous creation were applicable.

Further studies are being made of the diameters of a sample of the fainter sources, and this research is also aimed at the cosmo-

logical problem. The angular sizes of the most distant sources should decrease, stay constant, or increase with apparent distance, according to the choice of cosmological model.

A small amount of research is being done on the brightness distribution across a few of the sources. This fascinating problem has to be tackled by interferometry because of the small angular size of the detail to be resolved, but it is the nearest that the radio astronomer can get to the reproduction of accurate pictures of celestial objects. Small scale investigations are also proceeding on the polarization of the radiation from a few sources and their spectra. The spectra of most 'radio stars' are similar, in that the majority radiate much more strongly at longer wave-lengths, but the slope of the spectrum is not identical in every case. The spectra in general indicate that the sources are 'non-thermal' and this indicates that the mechanism of radiation is not thermal motion of the electrons in a very hot atmosphere. It is probable that the mechanism is synchrotron radiation.

Thermal Sources and the Planets

Thermal sources are those objects detected by radio astronomers which exhibit the characteristics of a hot body or gas radiating a relatively small amount of energy in the radio frequency spectrum. Surveys of the sky at centimetre and millimetre wave-lengths detect a majority of these sources. The temperature recorded from a thermal source will be equal to its true temperature if it is a solid 'black body', but will be somewhat less if it is partially transparent at the wave-length concerned.

The most familiar of the thermal sources is the quiet Sun, but this will be discussed under its own heading. The Moon is a thermal source and exhibits phases when observed in the millimetre and centimetre band, but appears to have a constant temperature at longer wave-lengths. It is thought that this behaviour is a result of the greater depth below the Moon's surface from which the longer waves are radiated; the dust layers act as an effective thermal insulator, keeping the temperature constant below the surface.

TABLE II

The Temperature of the Planets at Centimetre and Decimetre Wavelengths

Planet	*Wave-length centimetres*	*Temperature degrees K*
Venus	0·86	410±160
	3·15	560±73
	3·4	518±47
	3·37	575±58
	9·4	580±160
Jupiter	3·15	145±26
	3·2	177±22
	3·75	210±?
	10·3	640±85
	21·0	2,500±450
	21·1	3,000±1,300
	21·4	3,500±1,700
	31	5,500±1,500
	68	70,000±30,000
Mars	3·14	211±28
	3·15	218±76

Some of the planets emit thermally and the apparent temperatures that have been recorded to date are listed in Table 2. It should be noted that at very high radio frequencies Venus appears hotter than the temperatures recorded by infra-red detectors; this may be due to a very efficient hot-house effect, but this explanation is at present unproven. The apparent temperature of Jupiter is anomalous, and it appears that a non-thermal mechanism is probably responsible for the high readings at decimetre wave-lengths. It has been suggested that this may be radiation from some form of 'Van Allen Belt' around the planet. Jupiter also emits strong non-thermal signals in a narrow band of wave-lengths around 15 metres. These signals are in the form of sudden intense bursts, rather like atmospherics, but their origin and mechanism of radiation are not yet understood.

Other important thermal sources are the regions of ionized

hydrogen familiar to optical astronomers, in particular M8, M17, M20, the Orion Nebula, and a complex region in the direction of the centre of the Galaxy. The centimetre wave-length emission from these objects is proportional to the intensity of their hydrogen-alpha emission after correction for optical absorption.

The planetary nebulæ NGC7293 and NGC6853 have also been detected at 3·75 cm., and it is likely that radio techniques will prove a useful tool for determining the temperatures and electron densities of this type of object.

The Hydrogen Line

Originally predicted theoretically by Van de Hulst in 1945, the only spectral line that has yet been detected at radio frequencies from the Galaxy is centred on 1,420 megacycles per second (21 cm. wave-length), and is caused by the occasional reversal of the magnetic moments of the nuclei of the individual neutral hydrogen atoms distributed throughout interstellar space. The energy radiated by a single atom is exceedingly small, but despite the very low density of interstellar matter, the integrated radiation from vast regions of space containing molecular hydrogen is sufficient to give easily detected signals from certain regions of our own Galaxy and from a few of the nearby external galaxies.

In common with spectral lines at optical wave-lengths, the 21-cm. hydrogen line suffers an apparent change in wave-length when the source of radiation is in motion towards or away from the observer. This is the well-known Doppler effect. By measuring the wave-length or the frequency of the received radiation, it is possible to tell precisely the velocity of motion of the neutral hydrogen towards or away from the Earth. The neutral hydrogen clouds populate the spiral arms of our Galaxy, and as the arms are not rigid, the turns of the spiral are slipping relative to one another, producing a component of velocity relative to the Earth which may be measured with a suitable radio spectrometer. This fact, combined with the ability of radio waves to penetrate the dust that obliterates distant parts of the galactic plane at optical wave-lengths, has resulted in hydrogen line observations becoming the

major tool for the study of galactic structure. A detailed picture of the spiral structure of our Galaxy has now evolved from radio-spectrometer observations in the northern and southern hemispheres. The region in the very centre of the Galaxy is both complex and ambiguous, and though the situation in this region is rapidly becoming clearer, it is not so well understood as the outer parts.

The signal strength received from the neutral hydrogen is not very different if large or medium-sized aerials are used, as the sky temperature does not usually vary significantly over a few degrees of angle. The maximum temperature recorded corresponds to the true temperature of the neutral interstellar gas and is about 120 degrees absolute. Lower temperatures recorded from other parts of the sky are usually the result of radiation from regions which are not deep enough to be opaque to the radiation. Much greater *changes* in apparent temperature, and much finer positioning in angle, can be obtained by observing the spectral line in *absorption* in front of one of the stronger radio stars in the galactic plane. This technique shows up the individual clouds of hydrogen between the radio star and the Earth, and if the clouds are optically thick (to radio waves of this frequency), the temperature recorded is that of the radio star itself. Unfortunately there are not many radio stars which are sufficiently powerful to allow this technique to be used in many parts of the sky, but unlike the observation of hydrogen in emission, very big radio telescopes improve the observation in absorption by increasing the strength of the signal from the radio star and hence, in proportion, the signals absorbed by the gas.

The observation of hydrogen clouds in absorption has recently been put to use to endeavour to determine the magnetic field of the Galaxy. The fine strong spectral lines observed in absorption on the radio star Cassiopeia A are due to a few clouds in the intervening spiral arms. The presence of a magnetic field should result in a slight splitting of the absorption lines due to the Zeeman effect. This splitting is not directly measurable as it is less than the broadening of the lines resulting from random and turbulent motion of the atoms in the individual clouds, but the Zeeman

effect should still be detectable from the fact that the polarization of the radiation should be reversed on either side of the centre of the received absorption line. Up to the time of writing, this technique has shown that in the direction of Cassiopeia the magnetic field is less than 5×10^{-6} gauss.

Large radio telescopes are also necessary for the study of the neutral hydrogen emission from the galaxies. The Magellanic Clouds have been studied in some detail and there appears to be evidence of a 'bridge' between them and our own Galaxy. The Andromeda Nebula, M31, and about a dozen other galaxies, have been detected in emission. At one time it was thought that neutral hydrogen around the Cygnus A radio source had been detected in absorption, and it was claimed that this gave a measurement of the red-shift at radio wave-lengths. This observation has since been shown to be fallacious. Careful observations with the Jodrell Bank telescope have also failed to detect neutral hydrogen in intergalactic space.

The Sun

The Sun is the only true radio star that has yet been identified. It is intrinsically a thermal source and in its well-behaved state it is referred to as the 'quiet Sun'. The temperature that is measured varies with the wave-length at which the measurements are made, different wave-lengths of emission corresponding to different levels of penetration in the solar corona. At centimetre wave-lengths the temperature is of the order of 10,000° and the radio Sun does not differ greatly from the optical Sun. At metre wave-lengths the radiation comes from well out in the corona, and the radio Sun appears as a body a degree or more in diameter with a temperature of a million or so degrees, corresponding to the electron temperature of the corona at that distance from the Sun.

When the Sun is in an active or disturbed state, especially during the epoch of sunspot maxima, much more intense signals are emitted. These 'intense radiations' are divided into five different classes of phenomena under the general category of the 'active Sun'. The radiation in these cases is emitted from localized areas

in the proximity of the optically active regions on the Sun's disk, and most of the signals have a transient nature, varying from bursts lasting only a few seconds to enhanced radiation over a large area that may last for up to a few days.

Many of the active Sun phenomena are currently observed with solar spectrographs. These are very broad-band aerials connected to radio receivers which sweep over a number of octaves of the radio frequency spectrum and record their output by intensity modulation on a moving photographic film. A typical recording from a spectrograph may show the intense radiation at very high frequencies only momentarily delayed after a visible solar flare. The signals then spread to lower frequencies and die out at the high frequency end of the spectrum, giving the impression of an actual motion of the source outwards through the corona. Occasionally the spectral drift reverses, suggesting matter falling back into the Sun, and occasionally the outburst appears to carry with it a second component of the broad fundamental band of noise. Recent investigations have shown that the source of radiation in these outbursts does indeed move outwards, and occasionally inwards, through the corona; but it is not yet established whether this represents the actual motions of matter, or the excitation of different levels of the solar atmosphere by a shock wave, or similar disturbance, that propagates without bodily transporting the material.

The various classes of solar activity are listed in Table 3. It should be noted that the active Sun is often by far the brightest object in the radio sky at metre wave-lengths.

TABLE III

Solar Radio Emissions

Type	*Duration*	*Spectrum*	*Polarization*	*Location* etc.
Quiet Sun	Continuous	All wave-lengths	Unpolarized	Thermal radiation from chromosphere or corona
Condensations	Weeks	All wave-lengths	Unpolarized	Enhancements in corona
R centres	Hours or days	Long wave lengths	Circular	Sunspot radiation
Type I burst	Tens of seconds	Long wave-lengths	Circular	Near sunspots
Type II burst	Minutes	Dynamic spectrum, moving slowly from short to long waves	Unpolarized	Possibly associated with ejection of corpuscular streams
Type III burst	Seconds	Dynamic spectrum, moving rapidly from short to long waves	Unpolarized	Associated with large flares and probably with ejection of cosmic ray particles
Type IV burst	Minutes or hours	Noise storm over many octaves	Circular	——
Type V burst	Seconds	Dynamic spectrum wave-length rapidly decreases and increases again	——	Similar to type III

Recent Rocket Research

A. H. JARRETT

Introduction

Until the successful development of the war-time V2 rocket, man's direct investigations of the many phenomena of the upper atmosphere of the Earth had been limited to a few relatively brief flights by high altitude aircraft and balloons. One of the most famous pioneer attempts was that of the balloon *Zenith*, manned by T. Sivel, J. Croce-Spinelli and G. Tissandier, in which a height of about 28,000 feet was reached on 15 April 1875. A height of just over 70,000 feet was reached in 1935 by O. A. Anderson and A. W. Stevens, and, more recently, over 100,000 feet was achieved in 1959 by D. Simons. Unmanned balloons have been used on an increasing scale, since they are capable of carrying a useful payload to an altitude of 100,000 feet, and moreover remaining around that height for several hours. However, this altitude is effectively the limit for balloon-borne apparatus though considerably in excess of that for purely piston- or jet-powered aircraft in level flight. The V2 weapons attained a maximum height of about 100 km., but this is still very much within the range of the 1,000 km. or so which recent rocket experiments have shown to be the extent of the Earth's atmosphere.

In this article we are only concerned with the rocket as a means to an end, namely, the carrying of our apparatus to high altitudes. No attempt will be made to discuss the design of the rockets themselves. However, there are some factors which must be kept in mind, the chief of which is, perhaps, the short time of flight, generally of the order of five minutes. This, of course, means that information can only be obtained for, say, half this time, whilst

the rocket is in the upper part of its trajectory. In fact, prior to the International Geophysical Year, the total flight-time of all the rockets launched for experimental purposes, did not exceed more than a few hours. This leads to the need for very careful consideration of any envisaged experiment; is it really suitable for carrying a rocket? Naturally, any unnecessary increase in weight means a loss of peak altitude. It is unlikely that it would be the only experiment carried in the rocket, therefore it is important that it should not interfere with, or be disturbed by, any other piece of equipment. The design of suitable experiments is no easy matter, since recovery of the apparatus in an undamaged state is extremely difficult. Ingenious arrangements are made for the information gathered in flight to be transmitted continuously to a tracking station on the ground. This technique is known as *telemetry*, and is now so advanced that many channels can be dealt with simultaneously in the course of one rocket flight. A rocket cannot be launched just anywhere. Obviously, safety precautions are of paramount importance, but in addition extensive ancillary facilities are needed. For instance, the flight of the rocket has to be tracked continuously by electronic devices, complemented, when weather conditions permit, by optical methods. The kinetheodolite is extensively used in this work and is effectively an arrangement whereby photographs are taken through a telescope of the rocket in flight. Modern range facilities are complex and, together with the high cost of the rocket itself, make it absolutely imperative that any experiment considered as part of the payload must be exhaustively tested under laboratory conditions until it is perfect. We have to bear in mind that the failure of a single soldered connexion could mean the complete wastage of a vast amount of time and money. There are several experiments (e.g. for meteorological sounding purposes) which do not require very large, powerful rockets, and small rockets have been constructed which can easily be fired from ships without any of the normally accepted range facilities. The advantage of ship firings is that a launching base is available over a considerable latitude. These rockets are restricted to studies within the 100 km. height region.

The successful use of 'Sky-hook' balloons as launching platforms for relatively inexpensive rockets has been an interesting development. The rocket is fired automatically when the balloon reaches a height of about 15 km. The ensuing gain in peak altitude of the rocket is due largely to the elimination of the drag of the lower atmosphere. For instance, a rocket reaching a height of 20 km. when launched at sea level might reach a height of 90 km. when fired from a 'Sky-hook'.

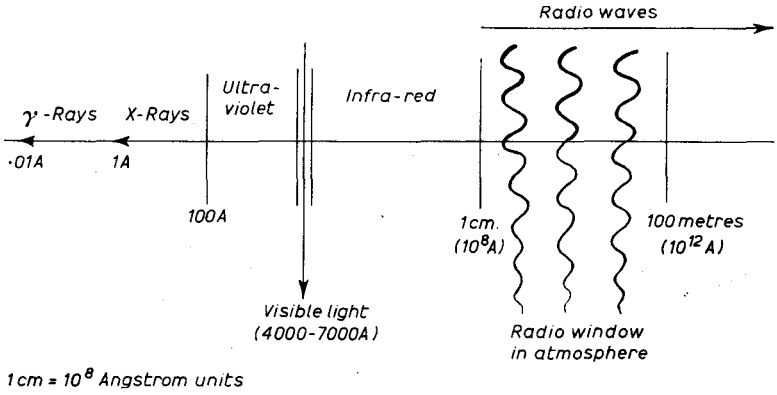


Fig. 1. *The electromagnetic spectrum and radiation windows in the Earth's atmosphere*

1. Solar Ultra-Violet and Cosmic Ray Experiments

The Earth's atmosphere filters off most of the radiation from the Sun. Fig. 1 shows that only a small fraction gets through to form the visible region of the spectrum; at sea level the atmosphere very effectively stops wave-lengths shorter than 3,000 A. The first important rocket experiment was to obtain photographs of the solar spectrum at different heights. At about 65 km. the wave-length range was extended down to 2,200 A. Clearly, for efficiency, the rocket-borne spectrograph must point at the Sun, not an easy accomplishment because of the motion of the rocket, which rolls and precesses in flight. However, sun-seeking devices

have been made and developed to a high degree of precision, and such a device led to the detection, for the first time, of the Lyman-alpha emission line of hydrogen at 1,216 A. Further experiments using rocket-borne photon counters have yielded information on the much shorter wave-length regions (soft X-rays). A knowledge of the direction in which the rocket is pointing is essential for many experiments, and can be obtained from photographs of the Earth's surface taken whilst in flight; studies of cosmic ray radiation are a case in point. Extensive launchings have been made at various geo-magnetic latitudes, the magnetic field of the Earth sorting out these high-energy particles in terms of their momentum. Arrays of Geiger counters have been carried aloft for this purpose, while special photographic emulsions, which are blackened by high-energy particles, have been flown to investigate highly charged nuclei in the primary cosmic radiation.

Very recently the realization of space probes, that is, vehicles capable of penetrating to many thousands of miles from the Earth, has led to the exciting discovery of hitherto unsuspected radiation called, after its discoverer, the Van Allen radiation. After previous extensive measurements of cosmic rays from high-altitude balloons and rockets, Van Allen suggested that artificial satellites could be used to measure cosmic radiation outside the terrestial atmosphere. The now famous Explorer vehicle was used, and the counting rate was found to increase by such a large amount that at high altitudes the Geiger counters jammed. Presently, when the satellite returned to lower altitudes, the counters commenced to operate again. Further flights with improved apparatus gave the situation shown in Fig. 2, from which we see that at a height of about one and a half times the Earth's radius, the counting rate is in excess of 10,000 particles per second falling on every square cm. This is reduced to a minimum around two and a half radii, thereafter rising to a further peak much in excess of 10,000 particles per square cm. per second at 3·6 Earth's radii. The Moon probe Pioneer III showed that the radiation then falls away slowly with increasing distance from the Earth. The diagram represents the state of affairs in one plane; for a complete representation one would have

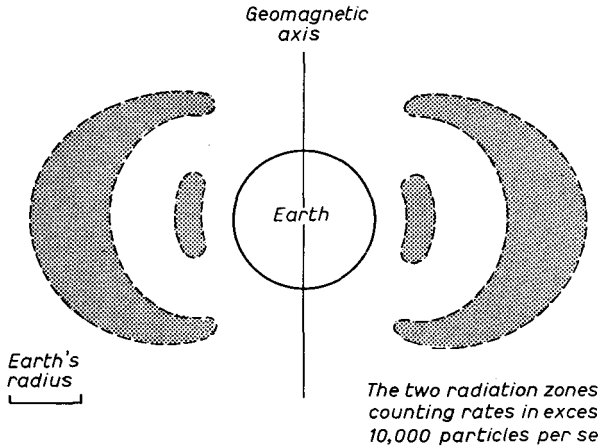

Geomagnetic axis
Earth
Earth's radius
The two radiation zones have counting rates in excess of 10,000 particles per second

Fig. 2. The Van Allen radiation belts

to envisage the diagram rotating about the geomagnetic axis of the Earth.

Further experiments with counters shielded by a thickness of lead demonstrated that while none of the particles in the upper radiation zone penetrated the shield, those in the lower zone did so easily. This leads us to assume that the lower radiation zone consists of high energy protons originating from the decay of neutrons formed in the upper atmosphere by incoming high-energy cosmic rays. The upper radiation zone most likely contains particles originating from the Sun. This conclusion is arrived at from the evidence that there are two kinds of particles which stream towards the Earth following an intense outburst, or 'solar flare' as it is called, on the Sun. One type gives rise to magnetic storms and auroral displays after a lapse of twelve to thirty hours; the other consists of primary cosmic rays, which take less than one hour to make the journey to the Earth. It seems likely that there is an appreciable magnetic field associated with the storm centre; consequently the emitted particles will take some of this magnetic field with them, as it were, and so form a magnetic link from the

Sun to the Earth. From the diagram we see that the outer Van Allen layer infringes over the polar regions of the Earth and some of the high energy particles associated with it will reach the 1,000 – 100 km. levels of the atmosphere and give rise to the auroral phenomena observed in high terrestial latitudes. The lower energy particles in the outer layer will be effectively trapped by the configuration of the magnetic lines of force converging at the poles. The highly complex motion of the trapped particles makes it very difficult to fix a period for their lifetime. Possibly it is of the order of a few weeks before leakage occurs; but until many more measurements can be made we are in no position to pronounce on this.

These radiation belts are of extreme importance from the point of view of manned space vehicles. The maximum intensity measured is around 50 roentgens per hour, and if we recall that the maximum safe dose is accepted as 0·1 roentgen per day, then we see that the radiation belts will have to be traversed very quickly, or alternatively, considerable shielding will be necessary for safety.

Mention has been made of the Lyman-alpha radiation from the Sun: it was in 1959 that the United States Naval Research Laboratory obtained the first picture of the Sun in Lyman-alpha light, using a spectograph mounted in an Aerobee-Hi rocket, at a height of 170 km. Photographs of the Sun taken at ground level in the light of Hydrogen-alpha (i.e. a wavelength of 6,563 A.), by means of a spectrograph or special filters, show bright regions, or *plages* as they are called, which indicate areas of sunspot activity. The regions on the Sun emitting Lyman-alpha radiations coincide markedly with the bright plages. Further work will possibly show that the Lyman-alpha activity varies in accordance with the well known eleven-year solar cycle. Rocket launchings have also been made to detect the X-rays emitted by solar flares, particularly with regard to their effect on ionization in the lowest of the ionospheric layers, or D-region as it is called (see Fig. 3). This is of importance in the study of radio communications as fadeouts invariably follow flare activity.

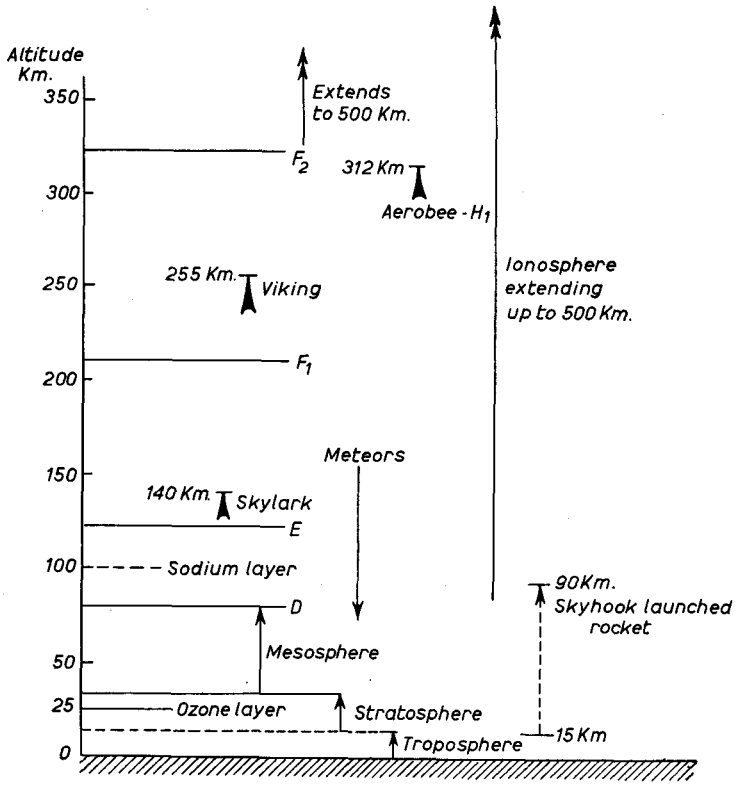


Fig. 3. The Earth's atmosphere

The first X-ray photograph of the Sun taken in 1960 at a wavelength of 20–60 A. was achieved by a simple pinhole camera with a piece of aluminium foil acting as a filter, carried by an Aerobee-Hi rocket to a height of 130 miles. Although the rocket was rotating during flight, the resulting smearing of the photograph did not prevent a reasonable amount of detail being recorded. The Sun appeared as a bright coronal ring, due to the generation of X-rays from collisions of coronal electrons with heavy nuclei; also there appears to be some X-ray activity within the coronal ring, presumably associated with intense solar activity.

2. Winds and Photochemical Activity of the Upper Atmosphere

Fig. 3 represents the various regions of the Earth's atmosphere, indicating the heights at which various effects take place. It shows very clearly that with rocket-borne equipment we have the possibility of studying many of its features. For instance the temperature is fairly well known up to an altitude of about 200 km. The heights attained by typical sounding rockets are marked on the diagram. The trails left by meteors as they burn up in the 160–120 km. region of the lower ionosphere are due to ionization of the residual elements in the atmosphere at that height. Some of these trails persist for several minutes and are rapidly distorted in shape, indicating strong winds at these levels. We will return to this feature shortly, but first must realize that the atmosphere retains almost the same composition up to a height of about 100 km. The chief difference is that the oxygen changes from the molecular form to the atomic form in the upper regions, and is highly active. Under the influence of solar radiation the atoms are excited to higher energy levels and then revert to lower states, with the emission of radiation. Because of this the night sky is never perfectly dark, quite apart from starlight, moonlight or auroral activity. This permanent radiation in the night sky is called the airglow, and although it is very feeble it can be analysed by sensitive spectrographs on the ground. Spectrographic studies proved the existence of a layer of sodium in the atmosphere at a height of about 100 km., and extensive work at several upper-atmosphere research stations showed a variation in the amount of sodium present at a given time. A spectacular way of examining the photochemical activity of the upper atmosphere was suggested by Professor D. R. Bates in 1950, whereby the atmosphere would be contaminated by suitable chemicals ejected from rockets. The release of two kilograms of sodium at heights ranging from 60–80 km. resulted in an intense glow readily visible to the unaided eye. The flights were made at twilight, the sodium vapour fluorescing because of its irradiation by sunlight. The sodium trail rapidly changed in form and photographs taken from several ground-based observing sites enabled the winds at these high altitudes to

be evaluated. This is considerably better than having to rely on the spasmodic occurrence of meteor trails for such a purpose. Another important outcome of the sodium trail experiment is that the temperature of the atmosphere at these heights can be found from ground-based observations on the light emitted by the trail. Briefly, these observations entail measuring the width of the sodium emission lines in the spectrum of the trail, for the width of such a line increases with the temperature of the radiation source.

Other airglow radiations are sufficiently strong to warrant their study by flying very sensitive photo-electric detectors, along with suitable filters, right up through the layers giving rise to the emissions. The idea is that the signal strength will increase as the rocket rises, reaching a maximum on entry of the rocket into the layer and then falling abruptly to background level as the rocket passes through the layer. This experiment therefore gives us a measure of the height of the emitting layer. Provided that the rocket can attain sufficient height, several photometers can be flown at the same time, the various signals being recorded through different telemetry channels.

The term airglow is reserved for the radiation from the night sky, as distinct from auroral radiation, but there is also radiation from the sky during the day-time. This day-glow can likewise be studied with rocket-borne photometers. Here there is the difficulty of the appreciable background radiation from the Sun. This means that the contrast between the background and the radiation under investigation is enfeebled, and to overcome this we use special filters, known as interference filters, which have the property of transmitting a very narrow band of wave-lengths. The centre of the band would correspond with the emission we are interested in.

3. Meteors

The study of meteors was revolutionized by the application of radar techniques, when a continuous day and night investigation became possible. The possibility of encountering even one small naked eye meteor during a rocket flight into ionospheric regions is extremely remote, but there are much smaller particles of meteoric

origin of only a few microns diameter. These extremely small particles slowly drift down towards the surface of the earth. Efforts to determine their number have been made in a variety of ways, such as examination of the sedimentation in the ocean and on snowfields in Antarctica, and attempts have been made to collect them using high-flying aircraft. The natural extension of this would be to arrange for the collection in a trap attached to a rocket, as by this means one would obviate the risk of including any particles of terrestrial origin. Unfortunately, the recovery of any rocket-carried trap would open up the possibility of contamination on impact. Obviously they are best detected as they enter the Earth's atmosphere, and two types of detectors have been devised; one relies on the impinging particle making a hole in a piece of thin metal foil, and the other depends on the momentum of the particle. An example of the latter method, which has been in use for some time, employs microphones so arranged that the micrometeorites fall on the diaphragm. Great care is necessary to prevent spurious microphonic effects arising from the connecting wires between the microphone and amplifier. The microphone is linked to a high-frequency amplifier to ensure maximum discrimination against noise produced by the structure of the rocket, its motor and payload. Normally several microphones would be installed in the rocket to decide whether a given signal arose from an actual meteor impact, or simply from local effects in the rocket. The possibility of two or more detectors being hit by meteorites at the same time is extremely remote. There appear to be many more of these micrometeorites than was at first expected.

Artificial satellites are well suited for micrometeorite experiments, since the effective counting time is enormously increased. Any meteorite penetration into the satellite leads to a pressure change, which gives an indication of the size of the particles. Recently artificial meteors have been ejected from rockets, producing trails over a range of heights to provide wind measurements. The known physical characteristics of the ejected materials enable us to check meteor theories. Meteor activity is extremely important from the point of view of space flight, and the danger

of encountering a meteor might be classed as an occupational hazard for future space travellers.

4. Experiments to Determine the Composition of the Atmosphere

The most important photochemical reactions in the lower atmosphere are the dissociation of molecular oxygen, the formation of ozone and nitric oxide, and the dissociation of water vapour. So far, only in the case of ozone have experiments been made on any large scale to investigate the distribution. Fig. 4

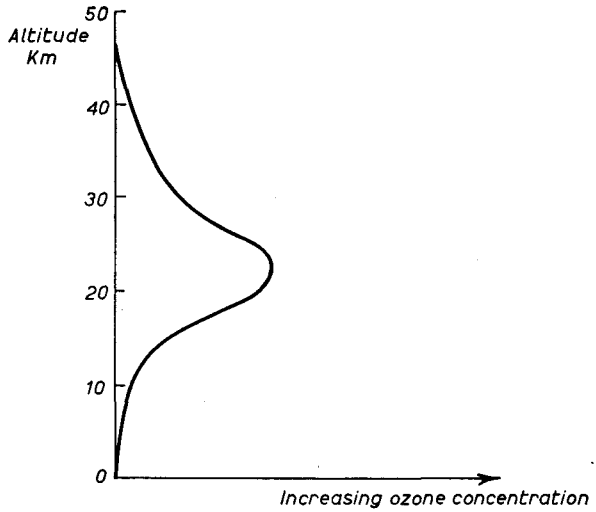


Fig. 4. Variation in ozone content of the Earth's atmosphere

shows the concentration of ozone with altitude. The maximum concentration of ozone occurs around 20 km. altitude. The absorption can be derived from variations in the solar spectrum taken at different heights. Ultra-violet spectrographs are normally used for this purpose, working at a wave-length around 2,800 A.

Around 1950 several firings took place in which evacuated steel bottles were flown in Aerobee rockets with a view to opening them at pre-set altitudes to collect air samples from the upper atmo-

sphere. Recovery was essential, then the contents were analysed. However, this method was not of wide application owing to the possible reaction of the active atmospheric constituents with the metal container. Later a mass spectrometer was incorporated in a rocket to analyse the atmosphere. Briefly, the charges of atmospheric ions are measured from the velocity they acquire in an electric field produced in the instrument. Preliminary results indicate that the mixing of the constituents, due to instability in the atmosphere, overshadows the separation which might be expected from diffusion effects, at heights of above 70 km.

5. The Ionosphere

Rocket launchings have been used to measure the ionization, or electron concentration, of the upper atmosphere. A radio transmitter is carried aloft in the rocket, and from measurements of the signal as received on the ground it is possible to work out the electron density. These results are of great use in the study of radio communications. Ordinary ground-based methods for finding the degree of ionization in the various layers are unreliable when the ion concentration exceeds a certain critical value, after which the radio waves are reflected, making the higher parts of a layer inaccessible for investigation. More recent work in this field makes use of radio transmitters carried in artificial satellites.

Considerable research has been carried out on the Earth's magnetic field. Experiments have been performed to look for discontinuities, which provide evidence of the flow of electric currents which are believed to give rise to the observed diurnal variations. Such discontinuities have been found with very high conductivities, nearly 1,000 times greater than previously calculated.

Rocket flights high into the atmosphere enable the magnetic field of the Earth to be measured, unaffected by local disturbances which influence ground based experiments. Here again artificial satellites are more suited to this work, first measurements indicating the flow of strong electric currents in the region of the

lower E-layer above the equator. This particular current flow is identifiable with the electrojet current, which was suggested on theoretical grounds, to explain diurnal variations in the magnetic field at the equator.

6. Artificial Satellites

Military development of the Intercontinental Ballistic Missile made available the high performance rockets necessary for satellite launching. The Russian achievement of Sputnik I, on 4 October 1957, marked the commencement of a whole new series of high atmosphere investigations. Important among these are geodetic determinations providing information concerning the shape of the Earth. Simultaneous observations of the satellite from several places yield valuable latitude and longitude determinations. Perturbations in the satellite's orbit reveal the composition of the Earth's crust.

The American weather reconnaissance satellite, Tiros I, was launched on 1 April 1960. The name Tiros is coined from Television and Infrared Observation Satellite. The infrared detectors will be used in future experiments to map the surface temperature of the Earth. The results of the 1 April launching were most impressive, in that cloud systems overlying very large portions of the earth were revealed by the television techniques involved. The televised photographs were of good definition considering the difficulties. Clearly the Tiros type of satellite will be of immense value to the science of meteorology. Since the object of Tiros I was extensive cloud observations, a circular orbit was arranged, as distinct from many other satellite orbits which have an appreciable eccentricity. The approximate height of the Tiros orbit was 450 miles. During the first week of its life Tiros actually detected a fully developed but unreported typhoon in the Tasman Sea.

Orbiting radio beacons could become most important in the field of navigation. The first step along these lines also took place in April 1960 when the Transit 1–B satellite was launched. Further experiments are in progress and will no doubt lead to a complete

navigation system with worldwide coverage. Incidentally, an interesting subsidiary experiment carried in Transit 1–B measured the Earth's albedo for infrared radiation.

7. Photographs of the far side of the Moon

Perhaps the most spectacular of all space probes was the Russian Lunik III launched on 4 October, 1959. Three days later photographs were taken of the Moon's surface on the side remote from the earth, from a height of about 40,000 miles above it. The films were developed automatically in the satellite and later televised over the telemetry channel. Although the photographs obtained were not of very high quality, the important thing is that they have been taken at all; obviously the resolution will improve in future experiments. In any case, prior to this historic flight only about three-fifths of the Moon's surface had been observed, whereas now three-quarters of the previously unseen face has been recorded.

8. First Steps into Space

The most challenging aspect of all concerning rocket and satellite research is undoubtedly that of manned space-flight. To this end much data is being accumulated. Several rocket flights have been made with animals in specially designed capsules, and successful recovery has been achieved in many cases. The second Russian artificial satellite, Sputnik II, contained the first true space traveller, a small dog called Laika. The dog was reported still alive after 54 orbits of the Earth, but unfortunately successful recovery did not take place. The important thing here is that the dog survived about 100 hours of weightlessness, and that the problem of suitable capsules providing living conditions has been solved. A later Russian experiment in which two dogs, Belka and Strelka, were successfully recovered from orbit was a further step along the road to manned space-flight, the most difficult part of which is possibly the successful re-entry of the satellite's occupants into the Earth's atmosphere. During 1961, as is well known, the first actual space-flights were made, the initial trip

being carried out by Major Yuri Gagarin of the U.S.S.R.

While the notion of manned space flight is most exciting, we must not lose sight of the fact that fully instrumented space probes will yield enormous quantities of information. The idea of the landing of instruments on the Moon opens up intriguing possibilities, for here we have a fine physical laboratory awaiting us, bombarded by all sorts of particles from space. An orbiting astronomical telescope, actively under consideration at the present time, is another entralling project.

As a result of the vast amount of rocket and satellite research, one thing is certainly emerging, namely, that a new era in astronomy is dawning, for we now have available for study a whole new waveband of radiation hitherto concealed from us.

The Origin of the Universe

PATRICK MOORE

The problem of the origin of the universe is probably the most fascinating in all science. Whether it will ever be solved is a matter for conjecture; meanwhile we can only take what evidence we have, doing our best to put the most rational interpretation on it. First, then, let us sum up the general position.

The Earth is a planet, moving round the Sun once in a year; the Earth-Sun distance, or *astronomical unit*, is 93,000,000 miles. The Sun itself is an ordinary star – one of perhaps 100,000 million such suns in our star-system or *Galaxy*. The Galaxy is of vast extent, and when we come to measure such distances we find that our ordinary unit – the mile – is inconveniently short. Instead, we shall here use the *light-year*, or distance travelled by a ray of light in one year. One light-year is equal to rather less than 6 million million miles.

The size of the Galaxy is known with reasonable certainty. From one side to the other, the system measures something like 100,000 light-years, while the 'width' is about one-fifth of this. We can see, then, that the Solar System is very insignificant in the Galaxy as a whole.

Even now we are only at the beginning; out in space we can see other galaxies, so remote that their light takes an immense time to reach us. One of the closest of them, the Great Galaxy in Andromeda, is faintly visible to the naked eye. Its distance is about 2 million light-years, and it is a member of what is known as the *local cluster* of galaxies.

Though the Andromeda Galaxy is a system even larger than our own, large telescopes are needed to show it well and to bring out the familiar spiral structure. With systems which are still more

remote, details are correspondingly more difficult to see. Many of the millions of galaxies which may be photographed with our greatest telescopes appear as nothing more impressive than tiny blurred patches, and it is not always easy to remember that they are in fact immense stellar 'island universes', to use an old term which is at least graphic. So far, the most remote galaxy whose distance has been measured by optical means is 3C–295, in the constellation Boötes (the Herdsman). It seems to be about 5,000 to 6,000 million light-years away, which means that the light from it now entering our telescopes began its long journey before the Earth existed as a separate body.

There is excellent proof that all the galaxies, apart from the members of our local group, are receding from us at high speeds. The further away they are, the faster they go; 3C–295, for instance, is moving away at a speed of 90,000 miles per second – half the velocity of light. Of course, these values are by no means certain, and may be subject to considerable errors, but we may at least assume that they are of the right order. The whole universe is expanding.

When we come to consider the time-scale of the universe, we find that we have to deal with figures which are just as difficult to appreciate. The Sun itself is several thousands of millions of years old, and it is clear that the Galaxy is older still, since it seems that the stars were formed out of material spread about in the form of 'clouds' or nebulæ.

Now let us turn back to the problem of the creation. The matter in the universe must have come from *somewhere*; it must therefore have been 'created', even though we have no idea of the exact process. According to theories of the *evolutionary* type, all the matter was originally contained in a super-dense 'primeval atom' which exploded, sending its material outwards in all directions. Expansion, the direct result of this outburst, went on for thousands of millions of years, until the whole universe had a diameter of perhaps 1,000 million light-years. At this stage things began to settle down, and clusters of galaxies began to form from the primeval material.

We know that gravitation tends to draw material together, and

one might imagine that as soon as the force of the explosion had spent itself, the matter in the universe would move once more to a common centre. On the evolutionary theory, this did not happen because of the existence of another force, cosmical repulsion, which acts in the contrary fashion to gravity. About 9,000 million years ago, some other disturbance tipped the scales in favour of cosmical repulsion; expansion began anew, and has continued ever since, because a larger universe means that cosmical repulsion will become more powerful while the opposing force of gravitation will become weaker. (Needless to say, cosmical repulsion becomes effective only when we are considering vast distances; over small areas, such as that of the Solar System or even our individual Galaxy, it may safely be neglected altogether.)

This idea is only one of the various evolutionary theories which have been put forward, but at least it accounts for the fact that the most distant galaxies recede from us at the greatest speeds. If it is correct, the universe will eventually die. Moreover, galaxies which lie at an immense distance will recede from us at a speed greater than the velocity of light, and will be unobservable.

In the late 1940s a group of astronomers working at Cambridge, notably F. Hoyle, H. Bondi and T. Gold, proposed an entirely different scheme. They rejected the primeval atom, and suggested that there had been no definite moment of creation; in other words the universe has always existed, and will exist for ever. As old galaxies die, new ones are produced from material created out of nothingness. This material appears in the form of hydrogen, the simplest of all the elements; the rate of creation is of course very slow, and so there is no hope of our detecting the new matter by ordinary methods. One might as well hope to detect the creation of a new grain of sand in the whole Sahara Desert.

If this idea of continuous creation is valid, the universe is in a *steady state*. It has always looked much the same as it does now, and it always will. The individual galaxies will not last indefinitely, but the numbers will remain more or less constant.

Of course, there is no clue as to how the matter is continuously created, but this is not, in itself, an objection to the steady-state

hypothesis. We are in equal trouble with the evolutionary theory, since nobody has been able to answer the question 'How did the primeval atom itself come into being?'

If we could look back in time, we might be able to decide between these two rival theories. If the universe is evolving, the galaxies used to be much more closely packed than they are now. If the universe is in a steady state, the average distance between individual galaxies has never changed. From this point of view, the situation is quite clear-cut.

We cannot go back in time, but we can at least study the universe as it used to be in the remote past. Consider two galaxies which are – say – 3,000 million light-years away. We are looking at them not as they are, but as they used to be 3,000 million years ago. This is the nearest we can get to 'time-travel', but it is a great deal better than nothing. If we could study galaxies which are sufficiently remote, we could see whether these systems are more closely packed than those closer to us. If there is an apparent crowding, the evolutionary theory must be correct; if not, then the steady-state theory wins the day.

Unfortunately even our most powerful telescopes will not probe far enough to give us a decision. However, radio astronomy has come to our aid. Visible light is only a small part of the total electromagnetic spectrum; the longer waves of the kind known as 'radio emissions' are collected by radio telescopes, of which the best known is the 250-foot instrument at Jodrell Bank. (By no means are radio telescopes all paraboloids of this sort, but all work on the same fundamental principles.) Some of the galaxies are powerful radio sources, and it is possible to detect radio waves coming from objects which are so remote that there is no trace of them optically. In other words, radio telescopes can reach out further than optical telescopes.

In 1955 a research team headed by M. Ryle, also at Cambridge, produced some results which showed that so far as radio sources were concerned, there was a definite 'crowding' at distances of the order of 6,000 to 8,000 million light-years. To be more accurate, these weak radio sources were more numerous than would be

expected if the steady-state theory of the universe were correct. The research clearly favoured the evolutionary hypothesis, and when Ryle confirmed his findings in 1961, from more precise measurements, there was a tremendous surge of popular as well as scientific interest.

Yet it would be premature to claim that the evidence is at all conclusive. For one thing the data are incomplete, and in any case not all galaxies are powerful radio sources; we still know nothing about the distribution of remote systems which do not send out such emissions in comparable quantity. The observations themselves are very delicate, and may involve large errors.

Yet it must be agreed that the steady-state theory has failed to stand up to its first direct test. It has by no means been disproved, but it has been decidedly weakened, and if the new results are confirmed by more detailed studies the whole idea of continuous creation may have to be either modified or else abandoned in its entirety. We can only wait and see what information comes to hand in the future. As soon as it becomes possible to build telescopes (both optical and radio) in space or upon a virtually airless world such as the Moon, our improved means of investigation should allow us to clear the whole matter up.

Even when this has been done, we will still be no nearer toward solving the real problem of the creation; nobody has any real idea of how matter can have been produced from nothingness. Moreover, there is the question of the time-scale. We cannot picture a period which has no beginning, and we are equally unable to imagine what can have happened before the universe started. The truth is that our minds are not yet advanced enough for us to solve fundamental problems of this kind.

Meanwhile the arguments between the supporters of the evolutionary and the steady-state theories continue unabated; every scrap of fresh evidence is dissected and analysed as thoroughly as is possible with our present techniques. We are still groping helplessly in the manner of a blind man in an unfamiliar house, but at least we have found out more than we could even have dreamed half a century ago.

Automation in Astronomy

ROGER GRIFFIN

Automation, like so many valuable products of scientific research, has only caught the public eye now that it has become a subject of political controversy. Although it reached the headlines only a few years ago, automation is a continuing process which, in one form or another, has contributed to the gradual increase in mechanization of science, industry and, indeed, of civilization as a whole, for generations if not centuries past.

Automation involves the replacement of men and women by machines. Naturally, this can be effected only in relation to specific tasks, since machines can be constructed to perform efficiently only one operation or at best a group of allied operations. This inflexibility of machines, this lack of that adaptive capacity which is so characteristic of human beings, implies that the highest degree of automation is likely to be achieved only in the most specialized procedures. We will see later that this general axiom is true in the particular case of astronomy. Where experimental results require evaluation in the context of a large body of information, perhaps from several different branches of a subject, that is the place for the scientist or craftsman; where a routine operation requires frequent repetition, there the machine comes into its own.

Most of the observational work in astronomy falls into one of three classes. First, we have records of the appearance of the sky and of objects seen in it (such as maps of star-fields, and of the surfaces of the Sun, Moon and planets). Secondly, we have *photometry* – evaluation of the brightnesses of stars and other distant objects. And thirdly, there are spectroscopic investigations, in which the light of celestial bodies is split up into its component

colours, with the object of discovering the chemical nature and physical conditions of these bodies, and also their movements with respect to the Earth. In all these categories, the human observer now frequently acts in a less direct manner than formerly. In charting the stars, and to a lesser extent in mapping planetary surfaces, his place at the telescope is often taken by a photographic plate; in photometry, his eye has often to give place to the plate, and more recently to the photo-electric cell; while in the observation of spectra the eye is at so great a disadvantage in comparison with the photographic plate that the latter has been almost universally used in such work for nearly a hundred years.

We may regard the introduction of the photographic plate to replace the draughtsman as one of the earlier instances of automation in astronomy. It must be made clear that it is only in such specific applications that photography represents a form of automation. Replacing a landscape painter by a camera does not automate landscape painting – because the painting is executed, not with the intention of producing an exact facsimile of the original view, but (until recently, at least) with the intention of enabling people unfamiliar with the view to capture some of the necessarily subjective charm which it held for the painter. To achieve the same end photographically may be possible, but in this case photography is simply the medium for another art form, the mastery of which may be fully as exacting (and rewarding) as the other. In the astronomical case, however, the desire is to create as accurate a likeness of the original object as is possible; and the application of photography permits the camera to perform exactly that task which would otherwise fall to the draughtsman – a true example of automation.

A second example of equipment which can effectively replace the human eye at the telescope is the photo-electric cell, or its more sophisticated counterpart, the photo-multiplier. This device, similar in principle to a photographer's exposure-meter, is capable of comparing the brightnesses of stars whose telescopic images are allowed to fall on it one by one. An electric current, proportional in strength to the brightness of the star, passes through the cell to

associated electronic equipment, where it is amplified and measured. The reading of the meter in the electrical circuit is a measure of the brightness of the particular star 'seen' in the telescope by the cell. The photo-electric cell may thus take over the duties of the astronomer, who has learned, by experience, to compare the brightnesses of two stars simply by looking at them one after the other.

At this point, the valid objection may be raised that while the photographic plate and photo-electric cell may indeed supplant the astronomer's eye at the focus of the telescope, they do not replace the astronomer himself; he is still just as necessary as ever, to guide and control not only the telescope, but now the camera or other equipment in addition. Apparently, therefore, there is no saving of manpower at all.

As a matter of fact, the advantages of automation are manifold, and in any particular instance they do not necessarily involve a reduction in manpower; neither does automation always involve relieving people of boring, tedious or repetitive tasks. Depending upon the particular application, it may result in greater rapidity (and consequently increased output); or in greater accuracy, or better sensitivity, or any combination of these desiderata. Moreover, the impersonality or lack of bias of a machine may be a real advantage. Suppose, for instance, we use a camera in conjunction with a telescope to provide a representation of the appearance of the Moon. In a single exposure, lasting perhaps a few seconds, there is captured on the sensitive emulsion such a wealth of detail as would take the draughtsman-astronomer weeks of painstaking work. In addition, the photograph will be objective, while the draughtsman is liable to err from time to time; and even the most conscientious draughtsman finds it difficult to put out of his mind what he has previously drawn, so that features which are near the limit of visibility in his instrument tend to become regarded as well-established in form – simply because they are represented in the same manner in successive drawings. The photo-electric cell provides an example of automation which brings with it enhanced accuracy and sensitivity; the human eye cannot distinguish be-

tween the brightnesses of two stars if they differ by less than about 10 per cent, whereas a 1 per cent difference is easily detectable by the cell, which can also measure the brightnesses of stars which are quite invisible to the eye through the same telescope.

The job of the astronomer, and more especially the professional astronomer, does not by any means consist solely of sitting up late at night at the small end of a big telescope in a cold and draughty dome, manipulating his equipment and communing with the stars. There is an element of truth in this naive picture in that 'observing' often forms part of the astronomer's routine; observing, however, is not an end in itself, but is simply the means by which an astronomer collects the raw material upon which to base his research. The larger and less romantic part of his work is done by day, in an ordinary office; and it frequently involves dealing with formidable quantities of numbers. It is at this point that automation can again help him; electronic digital computers are specially made to manipulate figures in accordance with any desired instructions. This application of automation in astronomy does indeed have the effect of saving manpower and of relieving the astronomer of an irksome task; and by sparing him tedious calculations, it leaves him more time and energy to devote to the more original parts of his research. It is not too much to say that the widespread use of high-speed digital computers is one of the most significant developments in the astronomical field during the past decade.

Many of the astronomer's measuring instruments are now adapted to feed computers directly, without intermediate handling of the data by the astronomer – another step toward complete automation. Of course, one cannot simply talk to the computer; the language it understands consists of small holes in a long ribbon of paper. The measuring instrument is so modified that instead of, say, giving a reading on a dial, it punches the reading in machine language, i.e. as the appropriate set of holes in the paper tape. When all the readings have been completed, the tape is removed and fed into the computer along with an instruction or 'programme' tape telling the machine what to do with all the numbers;

and in almost less time than it takes to relate, the desired results are printed out on a kind of typewriter operated directly by the computer.

As one specific example of such automation of astronomical measurement we may describe the determination of star positions from measurements of images upon a photograph of the star-field. When the plate is exposed, an image of each star is formed on the plate, to become visible as a cluster of silver grains when the plate is processed. The positions of these images upon the plate bear a relationship to the positions of the corresponding stars in the sky. The sky positions of some of the stars are usually known, and the problem is to determine those of the others. In principle the method of doing this is perfectly straightforward, but the labour involved in putting it into practice is enormous. This difficulty is particularly acute with regard to photographs taken by Schmidt cameras. Invented in 1930, cameras of Schmidt type can photograph large areas of the sky on one plate with excellent definition; and a single exposure, lasting perhaps half an hour, provides a plate showing tens of thousands of measurable star images. Measurement and evaluation of one plate might well occupy a whole observatory staff for months, and such plates are being accumulated nightly at observatories all over the world.

The first part of the progress toward complete automation as a means of solving this 'Schmidt problem' (and of reaping the benefits resulting from its solution) has now taken place in some observatories. The astronomer selects a star image and centres it on a cross-wire, either in a viewing microscope or else upon a screen on to which the image is projected; instead of writing down the two readings which specify the position of the image, he simply presses a knob which causes the readings to be punched on to paper tape ready for the computer. Later, this machine makes light work of the mathematics, which would be absolutely prohibitive if it were necessary to perform them manually. Although such techniques reduce the time taken to obtain the desired information from a photographic plate by a factor of ten or more,

they are still not nearly fast enough to keep up with the rate of production of excellent photographs.

The final stage of solving the problem lies, of course, in mechanizing the process of selecting star images and centring them upon cross-wires or equivalent marks. This is far from easy to do, but astronomers are actively exploring the possibilities in this direction. In a way, the process is peculiarly amenable to automation, since no skill or judgment is needed accurately to centre the star image; indeed, the freedom from personal bias of an automatic centring device may be expected to result in improved accuracy. Ultimately, one will hope to leave the measuring machine entirely alone while it measures all the stars on each plate, and the only human supervision which will be necessary will be occasional attention from an electronics maintenance engineer. Unless, indeed, it is then thought worth while to develop an automatic system of electronic servicing, automation in this particular field will then be complete.

Recent Research on the Moon

PATRICK MOORE

Because the Moon is so much the closest of the natural bodies in the sky, and because it is not veiled by any appreciable atmosphere, our knowledge of its surface is extensive. Yet it would be utterly wrong to assume, as some people do, that no problems remain to be solved. Even in fundamental matters of lunar study we still have a great deal to learn.

Until the last year or two, the Moon's surface features were studied mainly by amateurs using moderate telescopes. Now that the direct exploration of space has begun, and the first vehicle has landed on the lunar surface, professional astronomers, too, have started to pay attention to selenography, and a detailed photographic atlas has been produced in the United States by G. P. Kuiper and his associates. This atlas is of considerable value, but in some ways it underlines the weaknesses of present-day lunar photography, since the finer features are not shown sharply except in areas near the centre of the Moon's disk. In 1840, the French astronomer Arago stated that by using photography it would be possible 'to map the Moon's surface in a few minutes'. Arago was indeed wrong; 120 years later, the project is still incomplete.

In 1959 the Russian vehicle Lunik III went round the Moon, and sent back photographs of those parts of the lunar surface which can never be seen from Earth. Several of these pictures have been widely published, and suffice to show that there is no basic difference between the new and the old regions, except that the averted hemisphere contains fewer *maria* or seas. Further studies of the Lunik photographs have now been carried out in the U.S.S.R. by astronomers at Moscow, Kiev and Leningrad, and

Y. N. Lipski, at the Sternberg Institute in Moscow, has been able to produce a much more detailed map showing several hundreds of formations. The names allotted by the Soviet authorities seem to be very suitable; they include men such as Edison, Clerk Maxwell, Hertz, and – Jules Verne!

The Moon has been widely regarded as a world upon which no activity takes place. This view was shaken in November 1958, when N. A. Kozirev, using the 50-inch reflector at the Crimean Astrophysical Observatory, reported an outbreak inside the prominent crater Alphonsus. The observation has led to much controversy, but it is evident that some sort of disturbance did take place; Kozirev's spectrograms are quite conclusive on this point. However, it cannot be regarded as a full-scale volcanic outbreak, and was on a small scale judged by terrestrial standards. Its importance lies mainly in the fact that it proves that the Moon is not completely dormant. Previous reports of activity have been made, in Alphonsus and in other craters such as Plato, but this is the first time that such reports have been supported by spectrographic evidence.

The arguments about the method of formation of the lunar craters have continued. Many astronomers consider that the main craters were produced by the impacts of meteorites, while others consider that the large formations are basically volcanic. Kozirev's observation of Alphonsus tends to support the latter view, but it is certainly not conclusive, and the whole question remains open.

However, there are certain features on the Moon which seem certainly to be volcanic. These take the form of domes crowned by summit pits, and are strikingly similar to certain vulcanoids found on Earth. Since 1956 over sixty have been catalogued by the present writer; in 1959 G. P. Kuiper independently drew attention to a dozen of these.

In 1960 an interesting suggestion was made by J. J. Gilvarry. On this theory, the rocks of the *mare* floors are sedimentary, so that the Moon once possessed true oceans. Gilvarry points out that a small quantity of organic carbon in a sediment is sufficent to yield a dark rock of low reflectivity, and he accordingly

concludes that primitive life-forms existed in the lunar seas. The idea of past life on the Moon has not been widely accepted, but it is unlikely that the matter will be finally cleared up until it becomes possible to analyse samples of the lunar rocks.

Entirely different views are held by T. Gold, who believes that the *maria* are dust-filled, and that the drifts are many kilometres deep. He has shown that small dust-particles may acquire a sufficient electric charge to 'float' just above the surface, and to move downhill until they meet an obstruction, thereby producing a smooth surface which allows further dust to accumulate at low levels such as crater-bottoms. Gold supports the impact theory of crater formation, and believes that vulcanism has played at best a very minor rôle.

There are various objections to the dust-drift theory. It is not in accord with radio measures, which permit the examination of regions appreciably below the visible surface of the Moon, and various studies carried out by Russian astronomers, mainly at Leningrad, indicate that the actual surface is not smooth. It corresponds more precisely to 'rock froth' such as might be produced by lava eruptions. The Soviet astronomers N. Barabashov and A. Chekirda have suggested that the Moon is covered with a layer of disintegrated tufa-like rock, with grains ranging from 3 to 10 millimetres in diameter.

There seems to be no way of reconciling these two theories, but many authorities consider that the weight of evidence has now shifted against the dust-drift idea. Further information is needed, however, and this brings up the question of future developments in lunar study.

Careful measures are being made of the visible features; it has become clear, for instance, that the slopes of the inner and outer walls of craters are even more gentle than had been thought. Even more important are the studies of the polarization of the Moon's light, and of the luminescence of the surface; these researches will, it is hoped, lead on to a better understanding of the nature of the crust. Work on such lines is now in progress in Britain, France, America, Russia and elsewhere. Fresh attempts have also been

made to establish the presence or absence of a very tenuous atmosphere around the Moon, though so far the results are inconclusive.

Before long it is probable that more rocket probes will be sent round the Moon to continue the photographic mapping begun by Lunik III, and vehicles will also be landed on the surface. It would be of the greatest value to land a rocket gently enough to avoid damaging its instruments, so that it could continue to transmit information. There is every prospect that this will be achieved in the near future. Meanwhile it is pleasant to find that the Moon, so long neglected by all except a handful of skilful amateurs, has again become a centre of attention in astronomical research.

The Satellites of Jupiter

B. M. PEEK

All the major planets, with the exception of Mercury, Venus and possibly Pluto, are attended by one or more moons or satellites which revolve around them. The Earth is indeed the only one that has a solitary companion, the Moon, which is so large relative to its primary, that the Earth-Moon system might almost be regarded as a double planet rather than as a planet and its satellite.

Jupiter, which has roughly eleven times the diameter and 1,400 times the volume of the Earth, is attended by twelve such bodies, and it may be that others still await discovery. These satellites may be divided into two groups, the first comprising numbers I to IV and the second numbers VI to XII, with V not strictly belonging to either group.

Satellites I to IV were the first new objects in the Solar System to be discovered when the telescope began to be employed by Galileo and his contemporaries for the study of the heavens. They are commonly known as the Galilean satellites, since the great Italian astronomer is generally acknowledged to have been their discoverer. It may be noted, however, that Simon Marius claimed to have been observing them before the announcement reached him that they had been seen and studied by Galileo.

The numbering of the satellites from I to IV is in ascending order of their distances from Jupiter, from V to XII in order of their discovery. Since satellites VI to XII are very small and faint objects, all discovered photographically, and since their main interest to astronomers lies in the mathematical study of their orbits, considerations of space forbid more than a cursory reference to them here. They lie at far greater distances from Jupiter than numbers I to IV and fall into two sub-groups. The great

majority of the satellites in the Solar System revolve in their orbits in the same direction as that in which their primaries rotate on their axes; but VIII, IX, XI and XII, which compose the more distant sub-group, all have retrograde motions. They revolve at a distance of about 14 million miles from Jupiter, nearly twice as far as the inner sub-group, and take almost two years over each revolution. The shapes of their orbits do not remain constant owing to the strong disturbing effects of the Sun's gravitation.

Satellite V was discovered visually by E. E. Barnard in 1892 with the aid of the great 36-inch Lick refractor. The whole of its orbit lies exceedingly close to Jupiter, round which it revolves in only about twelve hours; although it is somewhat larger than any of the seven outer satellites it cannot be seen with small or even with moderate sized instruments on account of the overpowering glare from the planet. We focus our attention, therefore, on the Galilean satellites. In addition to their numbers these have been given the following names:

I Io	II Europa
III Ganymede	IV Callisto

Here we designate them by their numbers only.

All may be seen with the aid of quite small instruments, even with a good pair of binoculars, and the owner of a 2-inch or 3-inch telescope may spend many delightful and instructive hours in following their various configurations as they circle around the planet. Their periods of revolution, mean distances from the centre of Jupiter and diameters are shown in the following table the first being given in days, hours and minutes, the last two in miles.

Satellite	*Period*	*Distance*	*Diameter*
	d h m	miles	miles
I	01 18 29	262,000	2,000
II	03 13 18	417,000	1,800
III	07 04 00	665,000	3,100
IV	16 18 05	1,171,000	2,800

It will be seen that they are all of the same order of size as the Moon, whose diameter is 2,160 miles and which revolves at about

the same distance from the Earth as I does from Jupiter. Satellite III is actually about as large as the planet Mercury, while IV is only a little smaller. Their usual order of brightness is III, I, II, IV; for, although IV is considerably larger than both I and II, its surface is of a markedly duller hue. During their revolutions in their orbits each presents always the same face towards Jupiter, as the Moon does towards the Earth, with the result that, owing to the differing aspects of their surface features as seen from the Earth, they vary somewhat in apparent brightness and the above order is not maintained rigorously; III, however, is always the brightest. It is not yet known how strictly true it is that the same faces are permanently turned towards the planet; but many years would certainly have to elapse before any change would be revealed.

We may now consider some of the beautiful phenomena exhibited by these little moons. During each revolution they pass alternately between the Earth and the planet and behind the latter, the only one which, owing to its distance from Jupiter, may sometimes avoid this being IV. When a satellite is in transit between Jupiter and the Earth, it may often be seen with moderate-sized telescopes projected on the disk of the planet as a tiny dot, always darker than the central regions of the disk in the case of III or IV, generally dusky in the case of I but frequently bright when it is II. This shows that II, although it is the smallest, has actually the brightest surface of them all.

Far more intriguing, however, are their passages into and out of Jupiter's shadow, and the little black shadows which they themselves cast on the disk when they pass between the planet and the Sun. These phenomena may be observed with telescopes of 3 or even 2 inches aperture.

Since the Sun, the Earth and Jupiter do not in general lie in a straight line, the shadow of the planet, cast by the Sun, will appear from the Earth to lie sometimes on one side of the disk and sometimes on the other, with the result that the point where a satellite is seen to enter or leave the shadow may lie at some distance from the limb, which is the term used by astronomers to denote the edge of the disk. On reaching the edge of the shadow a satellite will be

seen to fade for no apparent reason and finally to disappear altogether, while it is still some distance away from the planet; or, where a moment before there was nothing, a minute speck of light may appear, to develop rapidly into a normally bright little moon as it comes out of the shadow into sunlight. The actual process of fading or brightening may take from about three minutes in the case of I up to, say, half an hour in the case of IV, depending for IV and in a lesser degree for the others on the directness or obliquity with which the shadow is encountered. As a rule, if a satellite is seen to disappear into the shadow, the reappearance from this eclipse will take place when it is behind the planet; conversely, if the end of the eclipse is visible, its beginning may have been obscured. But if the angle between the Earth and Sun, as seen from Jupiter, is not too small, both beginning and ending of the same eclipse may be observed on the same side of the planet when the satellite is III or IV and more rarely when it is II; this is never possible, however, in the case of I.

In all the leading Astronomical Ephemerides predictions are given of the times of beginning and ending of all the observable transits both of the satellites themselves and of their shadows across the disk, of their occultations behind the planet and of their eclipses by the shadow. A fairly comprehensive selection of these phenomena is also to be found in the annual *Handbook* of the British Astronomical Association.

It is perhaps well to emphasize that these phenomena are continually recurring and that they repeat themselves in order, over and over again, at intervals equal to the period of revolution of each satellite around Jupiter. If the observer will plot the positions of the four satellites on as many nights as possible for, say, a month and then place each of his diagrams below its predecessor at the appropriate intervals, he will find that the wave-like lines, which he will be able to draw through the positions of the individual satellites will present a most intriguing array. The curves of I, II and III interweave beautifully to form a pattern that repeats itself almost exactly in just over seven days, whilst that of IV goes its own lordly way without any reference whatever to the others.

The orbits of all the Galilean satellites lie very nearly in the plane of Jupiter's equator. As seen from the planet the directions of the Earth and the Sun never depart by much more than three degrees from this plane and they pass through it twice during every revolution of Jupiter around the Sun, that is, once in just under six years. When that occurs, the motions of the satellites appear from the Earth or the Sun to be backward and forward in almost straight lines that are very nearly identical; so there are clearly many opportunities for one satellite to obscure another by passing in front of it. When this would be seen by an imaginary observer on the Sun, the shadow of the nearer satellite must evidently fall upon the more distant one.

These very beautiful phenomena are known as mutual occultations and mutual eclipses respectively. They may be partial, total or annular, the last term being descriptive of the ring of light that remains visible if only the central region of a satellite is obscured.

On account of the conical tapering of the shadows most central mutual eclipses are annular. The shadow of III is the only one that has a large enough diameter to cause total eclipses; these must be of I or II and can occur only when they are traversing the nearer parts of their orbits.

There are one or two configurations of unusual interest that can occur in connexion with these mutual occultations and eclipses. It has just been pointed out that at certain seasons both the beginnings and endings of the eclipses of III and IV are seen to take place on the same side of the planet. At such times it is possible for one of the outer satellites, which is clear of Jupiter's shadow, to be occulted by one of the others that cannot be seen because it is undergoing primary eclipse. Again, if a satellite and its shadow are both in transit across the disk and the satellite is about to be eclipsed by the shadow of another, the second satellite need not be in transit, but it is clear that its shadow must be. The two shadows will approach one another and coalesce, when the first satellite, which may not have been easy to see before, will appear in projection as a conspicuous black spot.

The next series of mutual satellite phenomena will begin during the latter part of 1961 and will continue well into 1962. Predictions of the various occultations and eclipses of one satellite by another are being undertaken by the Computing Section of the British Astronomical Association and will be published in the appropriate numbers of the *Handbook*. It seems likely that this will be the only source of information for observers who wish to ascertain in advance the times when they should be on the watch.

Seen under sufficient magnification, say 300 diameters or more, and with sufficient optical resolving power, the satellites display little round disks that are quite different from the images of stars and their spurious disks and rings. Many attempts have been made to study the surface detail of these little bodies; but the observations are of great difficulty and little of value has been accomplished. Numerous drawings have been published, the majority of which have been executed with the aid of inadequate optical equipment, and the following consideration may assist the reader in assessing their value. During the progress of an annular eclipse of one satellite by the shadow of another a little black spot, the true shadow or umbra, should be seen near the middle of the disk of the eclipsed satellite. This appearance has been looked for on several occasions by experienced observers, using instruments of moderate power and aperture, but as yet it has not been seen. If, then, it is impossible for moderate-sized instruments to reveal a sharply defined black dot, how should they enable observers to portray the rather faintly shaded details that appear on many of the published drawings?

When we observe any of the phenomena of Jupiter's satellites, we see the events half an hour, more or less, later than they actually occur. This effect is, of course, allowed for in the predictions; but it is of interest to remember that it was the variation of the correction that has to be applied with the changing distance of the Earth from Jupiter that was interpreted by Rømer in 1675 as being due to the finite velocity of light and enabled him to make the first determination of that velocity, which today plays a fundamental role in almost every branch of physics.

Astronomical Photography for Amateurs

D. A. CAMPBELL

The amateur astronomer must often wish that he could make a permanent photographic record of some outstanding experience – a solar or lunar eclipse, perhaps, a meteor shower or an auroral display, the changing appearance of a comet on successive nights, or even the movement of a planet through a star-field. A great deal of satisfactory photographic work of this nature can be accomplished at quite low cost, provided that a study is made of the basic principles of the art, and that advantage is taken of simple workshop facilities in the construction of cameras and attachments.

The initial (and probably the most important) requirement for good astronomical photography is a really solid equatorial mount for the cameras and telescope. This mounting has one of its axes directed towards the celestial pole, so that a star may be followed in right ascension by a single circular movement about this axis. No effort should be spared to make this mounting, whatever its design or form, as rigid as circumstances and one's purse will permit. On this factor depends, not only normal enjoyable telescopic observation, but also any successful photographic work which may be undertaken. If the amateur does not already possess a knowledge of elementary photographic developing, printing and enlarging techniques, he should take steps to acquire some experience of these processes, so that he may make the most of his astronomical photographs.

The possibilities for this type of work fall broadly into the following divisions: (1) work with normal cameras; (2) work with

specially constructed star cameras; (3) work with cameras using the optical system of the telescope. Probably the first astronomical photographic exposure that the amateur makes is a star 'trailer' using an ordinary camera, stationary and pointing to the zenith, focused at infinity, with the exposure made for a period of 15 to 20 minutes. If a dew-cap has been placed on the lens to protect the surface from the condensation of the night-air moisture, the result will be a series of curved star-trails on the film or plate. Sometimes one may be so extremely fortunate as to obtain meteor trails on such exposures, which, under suitable conditions of development and printing, will show details of the structure of the trails. The passage of artificial satellites may also be recorded in this way, and interesting semicircular star-trails may be obtained if the lens is directed towards the Pole Star. Using suitable long exposures, the Aurora Borealis may be photographed with a fixed camera, and some very fine colour photographs of aurorae have been obtained with ordinary cameras.

During a lunar eclipse, a suitably oriented fixed camera may also be used to give ten or fifteen images of the Moon extending in a line across the plate and showing the various phases of the eclipse. The Earth's rotation will carry the camera through 15 degrees in the course of an hour; suitable exposures of $\frac{1}{2}$ to 2 seconds, made every five minutes by carefully removing and replacing a cover on the dew-cap, will result in fairly sharp images of the eclipsed Moon which may stand reasonable enlargement. Removing the cover from the dew-cap by hand is less likely to disturb the camera than using the camera shutter.

Photographs of star-fields require fairly long exposures, and the camera must follow the stars with a fairly regular movement if pin-point images are to be obtained. This is where the rigid equatorial mount is necessary. Postponing for the moment any discussion of the type of camera required, the instrument is fixed to a suitable platform on the mount. The axis of the equatorial should be capable of being turned by a handle driving a worm-gear or other form of slow drive. The operator can use his main telescope for guiding, or construct a smaller telescope, but in

either case the focus of the eyepiece should have fairly thick cross-wires. The telescope should be directed to a bright star in the centre of the star-field which is being photographed, and it should be slightly out of focus so that the diffraction rings surrounding the star's image centre on the cross-wire. During the drive for an exposure time of, say, 20 or 30 minutes, the eyepiece cross-wires should be kept on the centre 'target' of the star's diffraction rings. The exposure time may be signalled to the operator by a process-timer or alarm clock. The result, providing that the equatorial mounting is in good orientation, will be a star-field negative with nice pin-point images without any 'drift'.

While the amateur is engaged in the early stages of learning the technique of astronomical photography, the astro-camera can be of very simple construction. Rather than waste expensive plates and materials on the initial experimental exposures, it is well worth while constructing a camera with a simple lens, and using bromide paper instead of plates. At the turn of the century, quarter-plate magazine box cameras were popular; these had eight to twelve plate-holders which were arranged to drop down in sequence, and they are still available second-hand. If the original lens is removed, a simple plano-convex lens of 8-inch focus and about 2 inches aperture may be substituted, with adjustable focusing arrangements and a dew-cap and cover; no shutter is required, and bromide paper negatives can be held in the plate-holders behind clear quarter-plate glasses.

In order to adjust the camera to the best focus, one of the plate-holders should have an aperture cut in the back; a piece of ground glass is inserted in the plate-holder, with the ground surface in the plane of the paper, and with the back of the camera open, the focus may be checked on a bright star or planet. If this type of camera is not available, any light-tight box construction is suitable, which will hold the lens squared on to the bromide paper holder at the correct focus. The bromide paper is the blue-sensitive recording type of paper, which is fairly fast and from which prints can be made by copying, if necessary. The simple lens will give distortion on the edges of the field but should cover quite a few

square degrees of sky – for example, the whole of the constellation of Orion.

Graduating from this simple type of camera to instruments of better quality, the amateur has many war-surplus lenses to choose from. Short-focus lenses are suitable for wide-angle star fields, a typical example being the Ekta f/2 which covers a considerable area of sky. Cameras fitted with these lenses are ideal for meteor photography and minor planet positioning. In this latter connexion, a series of paper negatives of the area of the sky concerned, taken on consecutive nights, may be examined stereoscopically, when the minor planet's position among the surrounding stars will be obvious, owing to its movement.

For cometary work a longer-focus lens is advisable, and the guiding telescope should be focused on the nucleus of the comet, giving as long an exposure as possible. This will depend on the location of the observer, and will be governed by the extent of his local sky-fogging, and by the glare from house and street lighting, both of which, in these modern times, are severe. Obviously serious work can only be conducted by using plates in the cameras, but the manipulative experience gained while using simple cameras and paper negatives prepares the amateur for more advanced work.

The progress of sunspots across the Sun's disk can be made into an interesting photographic record, especially if it can be extended over the well-known eleven-year sunspot cycle. A telescope of quite modest aperture, with a home-made camera attachment, is capable of taking good solar pictures. The telescope is provided with a low-power eyepiece, and the camera is attached to the eyepiece tube. The camera consists of a suitable filter, a compur-type shutter with metal (*not* ebonite) shutter blades, a focusing screen and a book-type plate-holder.

A small finder telescope should be attached to the main instrument, and should preferably be provided with a coloured filter; it is arranged to give a $\frac{1}{4}$- or $\frac{1}{2}$-inch diameter image of the Sun, diverted at right-angles by a mirror on to a ground glass screen with suitable cross-lines scribed on it. Adjustments are made so

that a 2-inch diameter image of the Sun is formed by the eyepiece of the main telescope on the middle of the camera focusing screen, when the smaller image is on the cross-lines on the finder screen.

Great care should be taken to get the telescopic image in sharp focus by adjustment of the eyepiece, always bearing in mind the damage that may be done to the eye when viewing too bright an image of the Sun. Shutter speeds of 1/25 to 1/100 of a second, depending on the time of year and the clarity of the atmosphere, should be used. The telescope should be adjusted to a position just ahead of the Sun in its path across the sky. This gives time for all the vibrations on the mounting to die away, and the exposure is made when the Sun's image reaches the cross-lines on the finder screen.

Photographs of the Moon may be taken using a similar technique to that used for solar photography, except that no filters are required, and the exposures should be longer. A shutter is not necessary, and exposures of 1 to 3 seconds are best made by removing a cover from the front end of the telescope, thereby obviating all vibrations. The projected image formed by a low-power eyepiece may be used as in solar work, but for maximum definition the primary image, formed by the telescope objective or mirror, will give by far the best resolution. The size of the image will depend on the focal length of the telescope objective or mirror, and will generally range from $\frac{1}{4}$- to $\frac{1}{2}$-inch with amateur telescopes. If great care is taken in the initial focusing, by examining the image formed on the ground glass or matt-plastic focusing screen, the photographed image will stand reasonable enlargement. With modern fast film or plate stock and fine-grain developers, exposures may be short and, in the case of the Moon, good photographs may be obtained without following the Moon in right ascension on the equatorial.

Planetary photography is not very rewarding, except in the case of tracing the movement of the planets through the star fields, as described above. However, the primary image of the planet formed by the objective or mirror may be photographed, but, unless the aperture of the telescope is large and the focal length

long, the image of Jupiter or Saturn will be extremely small and will call for long exposures. This means careful following of the image. The image is blurred periodically by optical disturbances in the atmosphere, and various other factors make the operation difficult; nevertheless amateurs, have, with first-class equipment, obtained good planetary photographs.

The references given below contain very full advice on all these matters, the making of cameras, types of lenses, photographic techniques and explanation of the various optical problems that may be encountered. The reader's attention is also directed to current astronomical and photographic literature.

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The Crimean Astrophysical Observatory

PATRICK MOORE

Probably the most famous observatory in the U.S.S.R. is that of Pulkovo, near Leningrad. The climate there, however, is not favourable for astronomical work, and this also applies to Moscow. Consequently the Soviet authorities have wisely decided to concentrate the largest instruments in the southern part of the country, and particular attention has been paid to the Crimean Astrophysical Observatory, some way from the town of Simferopol.

The story of the Crimean Observatory began in 1900, when N. A. Maltsev founded a private research establishment at Simeis. In 1912 this became the official southern station of the Pulkovo Observatory, and thirteen years later a 40-inch Grubb reflector was installed. Unfortunately the Simeis Observatory was destroyed during the war, and was not restored until 1948. Meanwhile, the decision had been made to found a new station in the Crimea, and the first telescope of the new observatory was set up in 1949.

Nowadays the Observatory is excellently equipped. Studies of the Sun form an important part of the programme, and the Director, Dr A. B. Severny, is one of the world's leading solar physicists. There is an extensive astrophysical department, together with a radio astronomy section. Much of the equipment was built in the U.S.S.R. An exception is the 50-inch Zeiss reflector, used mainly for astrophysical research, but also used by N. A. Kozirev and others for studies of the Moon and planets.

Close beside the dome of the 50-inch is the new 102-inch re-

flector, the largest telescope in Europe and the third largest in the world. This is purely of Soviet construction, and was completed in late 1960. There is nothing revolutionary about its design – and neither is there any need; it has begun its work, and will certainly produce results of the greatest value.

At the moment an even larger reflector is being built. It will have a mirror 236 inches in diameter, so that it will surpass even the Hale telescope at Palomar, and is expected to be ready in six or seven years. Following exhaustive studies of possible sites, the Russian authorities have decided not to erect it in the Crimea, but in Central Asia, where observational conditions are even better.

Meanwhile, work in the Crimea itself will go on. The Observatory has established a great reputation during its comparatively short history, and it may confidently expect a no less fruitful career in the years to come.

Double and Binary Stars

J. C. VETTERLEIN

Double stars fall into two distinct classes. The term 'optical double' refers to a pair of stars whose components appear close together in the sky only because they lie in almost the same line of sight as seen from the Earth. There are many pairs of this type, in which the components often differ markedly from each other in apparent brightness, but clearly they have little astrophysical importance. It is the 'binaries' which give us so much valuable information.

In a binary system, the two components are genuinely associated, and lie relatively close together in space. Sometimes the two stars are so widely separated that they may be seen separately with a small telescope; in other cases the apparent separation may be so small that very large optical telescopes are needed to show the components individually. In fact, many stars known to be double are not separable by ordinary visual methods, because the components are too close together. Stars of this kind, known as *spectroscopic binaries*, are represented in large numbers in double-star catalogues. The components of visual binaries may themselves prove to be spectroscopic binaries, so that they form multiple systems. As is implied by the name, binaries of such a kind are measurable only by spectroscopic means, from which it is possible to compute their orbits. Here, however, we are concerned mainly with the visual binary stars.

The brightest star of a double is referred to as the *primary*, while the fainter component is the *comes*. The apparent relative positions of the two stars are designated as follows: the angular separation between the components is measured in seconds of arc,

while the other co-ordinate, the position angle, is the angle which a line drawn from the companion to its primary makes with the latter's circle of declination, beginning at the north and passing through east and south to west. The instrument generally used for making these measurements is the filar micrometer. Such micrometers have been in use for over 100 years, though with slight variations in design.

The first serious double-star measures were made by Sir William Herschel over 150 years ago, but the subject did not receive the attention it deserves until about 1820, when W. Struve began his double-star observations. Since then there have been many contributors to the work of discovering and measuring double stars. Struve's catalogue of 1824 contained over 3,000 pairs, most of which he had himself discovered. Other important contributions from the northern hemisphere came from an American amateur, S. W. Burnham, who discovered over 1,000 pairs and made an extensive catalogue including all the double stars known to him up to 1905; his *General Catalogue* contained 13,665 entries.

In England, two amateurs, T. E. H. Espin and W. Milburn, discovered 2,444 and 673 pairs respectively. The number of known doubles increased rapidly, and when R. G. Aitken set to work on his catalogue he rejected a great many of the wider pairs; nevertheless, his *General Catalogue of Double Stars* within 120 degrees of the north celestial pole contained 17,181 objects. Since Aitken's catalogue appeared, in 1932, many faint and difficult double stars have been added, but Aitken's catalogue is the last work of its type to have been issued up to the present time.

In the past there has been some disagreement concerning the attention which should be given to the remeasurement of known pairs, as opposed to the time which might be spent in discovering new ones. In any case, it is clearly necessary to correlate the work on an international basis – mainly in order to avoid neglecting certain important pairs, which happened during the earlier part of this century. The more recent discoveries of Hussey, Aitken and others means that powerful equipment has to be used for measur-

ing, and for this reason work on them can be carried out only at professional observatories.

Orbits of known binaries can be computed only when sufficient measures, covering a large appart of the parent orbit, have been accumulated. The various methods of orbit computation are given in standard texts such as *The Binary Stars*, by R. G. Aitken, and *Spherical Astronomy*, by W. M. Smart. Up to now, orbits have been computed for over 460 stars, and details of current work are regularly circulated by the International Astronomical Union's Commission for Double Stars. A rough analysis of the distribution of the known orbits among binaries in various catalogues clearly shows the trend and need of observations. Details are given in Table 1:

TABLE I

	Stars with Known Orbits	*Percentage in Group*
W. Struve	104	4
Otto Struve	48	9
Burnham	65	5
Aitken	115	4
Hussey	50	4

The W. Struve stars have been under observation for over 100 years. Consisting as they do of the wide, brighter pairs, one would expect a large proportion of optical pairs, together with binary systems in slow orbital motion. The 4 per cent of all Struve stars in this group probably represents 25 per cent of the Struve stars of binary character showing relative motion. The Otto Struve stars are generally more difficult to observe than the W. Struve stars, and hence the greater percentage of binaries is to be expected. All the remaining three groups are of more recent discovery, but already they have yielded a good percentage of binaries with determinable orbits. It is obvious that stars in these groups will give the greatest number of binaries, and that in view of their relatively high orbital motions they will need the most frequent attention.

For a number of binaries orbital elements have been computed

with such accuracy that they may be regarded as definitive (within the limits of observational uncertainty). Obviously, a good set of elements should allow the appearance of a double star to be determined for any time in the future. Any disagreement between computed and theoretical positions – once again, in excess of the unavoidable observational error – at once indicates an unsatisfactory set of elements. The computer who gives a new set of elements for a particular binary therefore usually gives a short ephemeris predicting the positions of the components, relative to each other, for some years to come. Table 2 has been compiled from some of the most recent elements given by computers. The period is given to the nearest year by the computer concerned; the values of distance and position angle have been computed, from the given elements, by the present writer, though in some cases they have been taken from the ephemeris of the computer himself. An effort has been made to list pairs not given in other recent publications such as the *Handbook* of the British Astronomical Association.

It may appear, therefore, that useful double star work may be carried out only by the professional astronomer. Yet this is not strictly true, for the following reasons.

It is clear that the number of close, difficult doubles on the professional programmes is very large, and that there are simply not enough observatories to cope with them. The wider pairs above 3 seconds of arc separation, and of approximately equal magnitude, are now measured photographically. This method is far superior to visual work, but once again there are too many stars to be dealt with. It would appear, then, that there still exists a field for research upon wider pairs of unequal magnitude, such as those in the catalogues of Espin and Milburn, where as yet no definite orbital motion has been established. It is also likely that many important pairs of separation between 1 and 3 seconds of arc are being unavoidably neglected.

The necessary equipment for this work could be provided by the really serious amateur. It has usually been assumed that double star work is possible only with the traditional refractor;

TABLE II

Ephemerides of Double Stars, 1962.0

ADS	*Name*	*R.A.* 1950·0 h m	*Dec.* 1950·0 ° ′	*Mags.*		*P.A.* °	*Dist.* ″	*Period* (*yrs.*)	
207	Σ13	0 13·4	+76 40	6·6	7·1	62·8	0·83	1600	H
588	*OΣ* 18	0 39·8	+ 3 54	7·4	9·5	187·5	1·32	335	S
1411	*OΣ* 34	1 44·3	+80 38	7·3	7·5	81·3	0·33	165	B
2122	Σ305	2 44·6	+19 10	7·3	8·2	310·6	3·56	720	R
2459	95 Cet	3 15·8	− 1 07	6·0	10·0	237·2	1·08	217	J
3093	40 Eri BC	4 13·2	− 7 41	4·0	9·2	346·6	7·53	248	V
3358	Σ566 AB–C	4 36·0	+53 23	5·4	7·4	247·9	0·97	306	F
3799	*OΣ* 517 A	5 10·9	+61 55	5·6	6·7	228·1	0·37	312	V
5559	38 Gem	6 51·8	+13 15	5·4	7·7	149·7	6·93	3190	Ho
5983	Σ1066	7 17·1	+22 05	3·2	8·2	218·4	6·37	1200	Ho
6175	α Gem	7 31·4	+32 00	2·0	2·9	157·2	1·91	511	M
6547	A 1581	8 00·7	− 6 16	9·6	9·6	110·3	0·54	95	B
6664	Hu 115	8 10·8	−13 45	9·0	10·0	130·0	1·13	59	B
6851	Hu 716	8 28·4	+35 08	7·0	8·5	120·3	0·48	33	C
7307	Σ1338	9 17·9	+38 24	6·5	6·7	227·1	1·20	389	A
7744	*OΣ*216	10 20·1	+15 36	7·0	10·5	289·0	0·97	250	B
9220	A 1102	14 17·0	+69 17	7·6	7·8	127·7	0·22	112	C
9343	ζ Boö	14 38·8	+13 57	4·6	4·6	308·9	1·17	123	W
9392	Σ1883	14 46·4	+ 6 10	7·0	7·0	94·2	0·36	280	B
9689	See 238 BC	15 30·2	−24 19	7·9	8·1	151·7	0·36	57	W
9692	Hu 577	15 30·6	+19 55	8·0	8·0	246·2	0·20	103	B
11334	Σ2315	18 23·0	+27 22	7·0	8·0	136·4	0·57	775	H
12447	Σ2525	19 24·5	+27 13	7·4	7·6	294·0	1·51	474	Fn
14360	Σ2729	20 48·8	− 5 49	6·3	7·6	3·9	0·97	147	H
15115	Hu 371	21 33·2	+24 14	7·0	7·5	274·9	0·25	174	B
15236	Hu 280	21 39·8	+ 5 41	7·7	8·1	285·4	0·12	115	B
15988	Σ2912	22 27·4	+ 4 11	5·8	7·2	117·3	1·06	143	So
16644	β 182 AB	23 14·5	−14 06	8·7	8·9	45·4	0·71	90	B
16649	β 79 AB	23 15·0	− 1 48	8·0	9·6	32·9	1·38	388	H
16659	Hu 400	23 15·1	+18 02	7·4	8·8	165·5	0·40	172	H

Authorities: A = Arend; B = Baize; C = Couteau; F = Fink; Fn = Finsen; H = Heintz; Ho = Hopmann; J = Jastuzebsh; M = Muller; R = Rabe; S = Sokolva; So = Sostrzebski; V = van den Bos; W = Wierzbinski

however, some observers have proved that excellent measures may be made with reflectors of 10 inches aperture and over, provided that the instruments are properly mounted.

Finally, much work remains to be done on the magnitudes of double stars. The values given by the Struves, for example, are generally very good, and any discrepancies with modern measures might well indicate that the star concerned is variable. This has certainly been established in a few cases. Amateurs are capable of doing such work, whether it be by photo-electric or ordinary visual methods, and it is to be hoped that at least a few serious observers will turn their attention to this interesting and useful field.

Solar Research

P. S. LAURIE

During the recent maximum phase of the Sun's cycle of activity, our attention was frequently drawn by the press and radio to some of the less obvious ways in which the Sun affects us. The events probably most often mentioned were solar flares. These are outbursts of energy associated with sunspots, the radiations which affect us being principally electromagnetic waves and particles. The former, reaching the Earth in not much more than 8 minutes, can cause strong ionization in the D-layer of the ionosphere and give rise to short-wave radio fade-outs. The visible light can be observed, although the most disrupting radiation is probably approaching the wave-length of X-rays. The particles (other than cosmic radiation), on the other hand, are much slower and take something between 18 and 36 hours to reach the Earth. If the Earth is enveloped in such a stream of particles, disturbances of the Earth's magnetic field are likely to follow. Knowledge of such effects has been built by careful observation over a long period. The historical basis of modern solar research from Galileo's day to the introduction of the spectroscope was founded on the visual observations of the dark sunspots during their passage across the Sun's disk.

From such observations the fluctuations of the sunspot cycle, the general behaviour of sunspots, the period of the Sun's rotation, the position of its axis and other facts have been established.

Many of the early observations were sporadic and none were carried out long enough to show the approximately eleven-year cycle of solar activity. However, by the middle of the nineteenth

century so much solid work had been carried out by Schwabe, Wolf, Spoerer and Carrington and his associates that a firm foundation for detailed inspection was laid. The introduction of photography led to the beginning of continuous series of solar photographs, such as that compiled at Greenwich.

All these observations had been carried out in white light, but the application of the spectroscope to solar investigation and the invention of the spectroheliograph by Hale and Deslandres in 1891 gave great impetus to solar research in the light of various elements of the Sun's constitution, such as the strong Hα line of hydrogen in the red region of the spectrum.

As the Sun is largely composed of hydrogen, it is comparatively simple, by means of the spectroheliograph, to photograph features on the Sun's disk and prominences at the limb. An extension of the latter instrument, the spectrohelioscope (again invented by Hale) brought such features into the visual range of observations. These observations were improved yet again by the introduction, a decade ago, of Lyot's brilliant birefringent filter.

Rather than pursue a catalogue of names and events, I should like to describe the instruments and a typical day's work in an observatory dealing, as part of its programme, with the observation of sunspots and solar flares.

The solar equipment is conveniently situated in a smallish building situated on a low hill overlooking a wide tract of level land, giving an excellent horizon from east, through south, to west. The building contains a suitable room for spectrohelioscopes, dark rooms and a general office containing the measuring machine for dealing with large-scale photographs of the Sun; the whole is surmounted by a 22-foot dome housing the telescopes used for obtaining the basic data.

On arrrival each morning, our first job is to open the dome and make a preliminary visual observation of the Sun to see whether any major changes have taken place since the last observation. In the centre of the dome is a solid pier rising through the building from substantial foundations some feet below ground level; this pier is separated from the flooring by a small space to avoid

vibration. On the pier stands our principal instrument, an equatorially mounted 6¼-inch refractor to which is attached a second telescope of 4-inch aperture; the two are mounted like an 'over and under' double-barrelled gun. The smaller telescope is a photoheliograph, the basic instrument with which large-scale photographs are obtained in white light, and has an object glass of 5-feet focal length, a focal plane shutter and spider threads (for the orientation of the photographs), an enlarging system and a camera box with a ground-glass screen on which falls an image of the Sun some 7½ inches in diameter.

Having started the drive (to counteract the rotation of the Earth) and swung the instrument on to the Sun so that its image is accurately centred on the ground-glass screen, we should briefly scan the disk before setting the shutter for the appropriate exposure; in summer this only amounts to a few thousandths of a second. The screen is then removed and a carrier containing a 10-inch by 10-inch photographic plate substituted. The emulsion used is slow, of very fine grain and high contrast.

Two plates are normally taken if weather conditions are favourable, so that we have a duplicate for checking purposes – and an insurance against accidents. If conditions are poor, it is well worth waiting for an improvement in 'seeing' before taking the second photograph. On the other hand, it is very sound practice to take one, if possible, however poor the sky.

To the 6¼-inch aperture telescope is attached a Lyot birefringent filter used for isolating the Hα line. There is plenty of light to photograph the whole Sun in this wave-length only, even though it represents only a very small fraction of the Sun's light. As this filter has to be heated to its correct working temperature and takes about 10 minutes to reach it, the heating element will have already been switched on as one of the preliminaries before taking the white light photographs. The filter produces an image of high resolution in Hα light, showing the areas of bright and dark hydrogen flocculi as well as prominences at the Sun's limb, or edge, outlined against a black background. Although useful visual observations can be made, the filter has a 35-mm. camera attach-

ment which enables us to obtain a permanent record of the Sun's activity. The camera control, which can be operated manually, or automatically at pre-set intervals, has a light meter built into the circuit ensuring a correct exposure, irrespective of adjacent cloud. To avoid getting too much light reflected from clouds or diffused by a hazy sky, the photo-electric cell has a small telescope attached; this covers little more than the Sun and thus measures very accurately the amount of light received. The film used has a special emulsion with high sensitivity around Hα.

Even if there is no particular activity seen when the Sun is viewed through the filter, it is part of routine procedure to take several photographs of the disk and limb features, the latter being so faint that they require some eight times the exposure needed for the bright disk; the latter amounts to about half a second for a summer Sun.

Having now obtained the basic observations in white and Hα light, the former are developed in a caustic hydroquinone solution which gives a high degree of contrast to the negative.

Normally, the plates will be dry by the afternoon when the better one will be chosen for the permanent record and the other kept as a duplicate. After being labelled with the date and time of exposure, they are filed in manilla envelopes. When a series has been taken, the plates are placed in order in a large frame and the sunspots and faculæ (areas of bright hydrogen visible in integrated light near the limb) are marked out as a day by day record. As the Sun revolves about its axis in about twenty-seven days, a fortnight's plates are required to trace an individual spot group during its transit across the disk.

Measurement of these plates is a matter of daily routine, which must be strictly adhered to unless the work is to fall into arrears.

The plate next to be dealt with is centred in a large micrometer specially built for the purpose, the position angle from the Sun's north point and distance from the centre of the disk being accurately measured for all spot groups (to 1/10 of a degree and 1/250 of an inch, respectively). The area of each spot is measured by means of a graticule fixed in the eyepiece of the micrometer. A

single photograph taken at the most active phase of the sunspot cycle may entail the measurement of from 75 to 100 positions and areas. These, when reduced, give the heliographic latitude and longitude of each spot group, and its area corrected for the effects of foreshortening, expressed in millionths of the Sun's visible hemisphere. Daily results such as these build up the life histories of sunspots and are eventually published in some suitable form, complete with a general catalogue for the year and summary tables containing details of mean latitude, distribution, and so forth. These annual results are on sale at small cost and form the basis for long-term statistical investigations. The Sun is, of course, a star, but it is the only one near enough for us to examine its surface features and detailed behaviour, and to be affected by its fluctuations, hence the importance of its observation.

During the day the Sun has to be kept under constant observation when possible and two or three photographs an hour are obtained with the Lyot filter so that any solar flares which may occur are not missed.

In the event of a considerable flare being observed, a series of photographs at intervals, sometimes of a few seconds, are obtained from which it is possible to derive the time of beginning, maximum intensity and return to normal conditions. The filter is admirably suited for obtaining the areas of flares (the importance of a flare is largely based on its area) and, by the introduction of a step wedge, a fairly good assessment of its intensity in terms of the continuous spectrum can be made. The increase in width of the Hα line and line of sight velocities of possible dark markings associated with a flare are best observed visually with a spectrohelioscope, in which the Doppler effect is utilized to obtain the velocities.

In this instrument a diffraction grating produces the spectrum (just as raindrops produce the rainbow) and the Hα line is then isolated by a narrow slit. Situated in a darkened room with a small opening through which the sunlight is directed, the spectrohelioscope can be used simultaneously with, and as a useful adjunct to, the Lyot filter.

Yet another useful instrument can be used to time flare effects

on the ionosphere. This is a recorder of the sudden enhancement of atmospherics which are brought about by flare radiations. This piece of apparatus consists of a radio receiver tuned to about 26 Kc/s, on which frequency there is a considerable increase of background noise due to the ionization of the D-layer. Coupled with this recorder is another set tuned to a normal short-wave station (say about 6 Mc/s). When a flare occurs which has sufficient energy to affect short-wave radio, the fact is clearly shown by the pens of the recorder, the enhancement of atmospherics coinciding with the drop in signal strength of the normal short-wave transmission. This recorder, of course, functions irrespective of cloud and gives a good indication of general flare activity, even though it may not be possible to photograph the Sun at the time.

Quite apart from these routine observations and regular publication of results, there remains an important service to be rendered by the solar department of an observatory and this is the close co-operation (by means of current information) with institutions or individuals engaged in work which can be seriously affected by solar activity. These naturally include geomagneticians and radio engineers, to quote but two categories. The latter, in particular, can be prepared to take evasive action from fade-outs which may sometimes seriously affect world radio communications.

Apart from local arrangements for the distribution of information, most observatories send their results to a collecting centre where the data are collated and published. Solar observations, for example, normally appear in the *Quarterly Bulletin* of the International Astronomical Union. During the International Geophysical Year and the International Geophysical Co-operation periods which followed, however, special World Data Centres were set up to undertake this large piece of work.

The recent sunspot maximum, which reached its peak at the end of 1957 and beginning of 1958, was covered by the world-wide observations carried out during the I.G.Y. This coverage enabled the Sun to be observed for nearly 90 per cent of the eighteen months during which exceptional efforts were made to keep it under constant observation. Not only was great effort put into the

'flare patrol' by many observatories throughout the world, but completely new techniques were employed, outside conventional observing methods, including the use of satellites and rockets. These have resulted in the discovery of belts of high-energy particles around the Earth, trapped within its magnetic field.

The 1957–58 maximum phase reached the highest level of solar activity since reliable records began well over a century ago, and was characterized by the very large number of moderate-sized sunspot groups rather than by individual groups of outstanding size.

From the previous minimum in 1954, the sunspot curve rose extremely steeply until the middle of 1956. Although the rise then became slightly less steep, the build-up continued steadily until the end of 1957 when the peak of the present cycle was reached.

It was not until the middle of 1959 that activity dropped to a level comparable with the peak of the previously highest recorded maximum (1947–48), the Sun having remained more active than at any other recorded period for nearly three years. The first signs of a really decisive decline did not become apparent until the last quarter of 1960, when most aspects of activity dropped fairly steeply. Taken as a whole, the Sun was half as energetic in 1960 as it was at the peak of the cycle.

Activity in 1961–62 should, of course, be on a much reduced scale compared with 1957–58; the next minimum can be expected in 1964–65, always provided that the rest of the cycle behaves in a normal manner.

Minimum phase is, naturally, a time for solar physicists to carry out investigations, prohibited by pressure of observational work at other times, and make good use of the data accumulated since the last minimum.

It may be fitting to end with Hale's remark on the purpose of solar observation: 'The investigation of the Sun as a typical star in connexion with the study of stellar evolution, and as the central body of the solar system, with special reference to possible changes in the intensity of its heat radiation, such as might influence life upon Earth.'

Astronomy at the Science Museum

H. R. CALVERT

1. Origin and Early History of the Collection

The collections in the Science Museum were started more than a century ago as teaching collections for the Science and Art Department at South Kensington. More material was acquired from international exhibitions such as those of 1851 and 1862, and above all, from the Special Loan Collection of Scientific Instruments of 1876; the Patent Museum also added exhibits to the collection in 1844. What was collected was not by any means mainly astronomical material but, along with physical apparatus, there were telescopes, globes and astronomical models which later formed the beginnings of the present Astronomy Collection. As the museum grew there was a snowball effect; manufacturers and private individuals, knowing of the collection, offered more exhibits to be shown in it.

Until 1928 the collections were housed in buildings which had been erected for such temporary exhibitions as the International Exhibition of 1862. The astronomy exhibits were lumped together with those from the rest of science as the Science Collections. But in 1928 the Eastern Block, the first building in this country to be specially constructed for a Science Museum, was formally opened by the King, and from that time an area in the galleries was set aside exclusively for Astronomy.

In preparation for the move into the Eastern Block Mr (later Sir) H. Spencer Jones was asked in 1924 to submit a scheme for the contents and arrangement of the Astronomy Collection. With characteristic thoroughness he prepared a closely typed report running to thirty-three foolscap sheets, which covered the whole

subject of exhibits relating to the history and development of astronomical instruments and astronomical phenomena. He wrote, 'Astronomy is a subject which does not lend itself particularly well to representation by models. Considerable use must be made of photographs and transparencies.' He did, however, add that 'In the case of many of the earlier and simpler instruments models could be constructed without difficulty to show the main features . . . Opportunities of acquiring originals or replicas of historical instruments should be utilized, as these add interest to any collection. Important historical instruments might in some instances be obtained on loan.'

Much of Spencer Jones's scheme followed J. S. Repsold's 'Zur Geschichte der Astronomischen Messwerkzeuge', and his suggestions have formed the basis of the arrangement which is now to be seen in the Museum.

2. Scope and Contents of the Collection

There are two main divisions in the collection.

(i) Astronomical Instruments, and (ii) Descriptive Astronomy

(i) INSTRUMENTS

(*a*) *The Telescope*

Much of the collection of instruments illustrates the history and development of the telescope, from Lippershey to Palomar. Where actual instruments are not available, pictures and photographs have to be used. Facsimile models of Galileo's and Newton's telescopes are shown. By the generosity of the descendants of Sir William Herschel the Museum has acquired much original Herschel material including his first 4-foot speculum, two 7-foot telescopes, one 10-foot telescope and many eyepieces and accessories. Herschel's telescopes had a ratio of aperture to focal length of about one-tenth, so that the 4-foot speculum was mounted in a 40-foot tube supported on a large and elaborate scaffolding in the grounds of Observatory House at Slough, only recently pulled down. The 4-foot speculum weighs half a ton and was cast in 1785.

For sixty years it was the largest telescope in the world until Lord Rosse constructed his 6-foot reflector at Birr Castle near Parsonstown in Ireland. Lord Rosse's speculum, which in its turn remained the largest in the world for about seventy-five years, is also exhibited in the Science Museum. Its weight of nearly 4 tons makes it too heavy for the upper floors of the museum, and it has to remain on the ground floor divorced from the related exhibits, such as eyepieces, secondary mirrors, grinding tools and a delightful model of the whole telescope. All of these, which were presented by the Earl of Rosse in 1914, are shown in the Astronomy Gallery on the top floor. In addition to the large telescopes there is a very good collection of small telescopes, especially Gregorian reflectors of 2 or 3 inches aperture illustrating the work of many makers at different periods of time. There is one made by John Hadley in 1726 and another made by Benjamin Martin. This latter was used by Professor Winthrop of Harvard College, U.S.A. and is the only scientific instrument of any sort which is known to have survived the fire at Harvard in 1764, when all their science buildings were destroyed.

The purpose of some of the telescopes exhibited is to illustrate the types of mountings which have been used, such as mural quadrants, transit instruments, equatorials, equatorial coudé, altazimuth mountings and zenith telescopes.

(*b*) *Accessories to the Telescope*

Attempts are made to indicate the historical development of such accessories to the telescope as artificial horizons, micrometer eyepieces, divided object glasses and spectroscopic apparatus.

(*c*) *Sundials*

Although the Museum has a separate section devoted solely to 'time measurement' there is quite a large collection of sundials in the astronomy section. This is justified, if justification is needed, by the fact that the apparent motion of the Sun is an astronomical problem. The collection of sundials shows how various instrument makers have tackled the same basic problem, and the many signed

and dated examples help with the dating and identification of newly found specimens which are submitted to the Museum.

(d) Instruments for measuring angles

Before the advent of the telescope practical astronomy consisted almost exclusively of measuring the relative positions and variation in angular separations of the heavenly bodies. The types of instruments used for this work are shown in the collection, namely, astrolabes, cross-staffs, back-staffs, quadrants and sextants.

(ii) DESCRIPTIVE ASTRONOMY

Descriptive astronomy, the results of the observations and the theories underlying them, are difficult to convey by exhibits, as Spencer Jones remarked in his report, and the Museum makes no attempt at a complete exposition of the subject.

The backbone of this part of the collection is a series of positive transparencies enlarged from photographs obtained with large telescopes to show the skies and heavenly bodies. These are grouped into sections dealing with Sun, planets, meteors, comets, nebulæ, stars and so on.

In addition to the photographs there is a collection of celestial and terrestrial globes and armillary spheres, and some globes and models showing the features of the Moon and Mars. Orreries of all periods from the beginning of the eighteenth century show that working models of the solar system have always been popular. One instructive exhibit, which seems to bring home to visitors the meaning of astronomical distances, is a model of the solar system to a scale of 1:4,000 million. The Sun is represented by a luminous glass sphere of 14 inches diameter and the other bodies, true to scale, are placed at various points along the gallery. Only Mercury, Venus, Earth and Moon can be shown in their correct positions within the limits of the gallery. The positions of the other model planets are indicated on a map which shows, for example, Saturn at Brompton Oratory, and Pluto nearly at Hyde Park Corner, almost a mile from the Museum.

One model shows the path of Halley's Comet and another the

distribution of the globular star clusters according to Shapley; but on the whole it can be said that such models convey little which cannot be done in a text-book by diagrams and pictures.

The exhibit which gives rise to most correspondence and inquiries is the Foucault pendulum. This slowly swinging pendulum, 79-feet long, hangs in a prominent position in the main entrance hall, so that it is seen by most visitors and awakens their curiosity and interest.

3. Future Developments

It is intended that within the next few years the astronomy collection will be moved to the first floor of the Centre Block, a large extension which is now under construction. Until the move takes place there will necessarily be a certain amount of disorganization of the collection because preparations for the new display have already had to be started.

A small hemispherical star-dome 20-feet in diameter has been erected and furnished by the Ministry of Works. It is placed at present in the centre of the existing Astronomy Gallery, but is so designed that it can be dismantled for removal and re-erection in the Centre Block. A Zeiss instrument projects the stars – down to the sixth magnitude – on the inside surface of the dome. Driven by a motor at the rate of one revolution in about 4 minutes, the projector shows the diurnal and annual motion of the stars for any place in the northern hemisphere; the effect of precession can also be demonstrated. Although Sun, Moon and planets can be included in the picture there is no mechanism in the instrument to move them relatively to the stars. The instrument has been shown regularly to visitors since April 1960.

Another exhibit which will be shown in the Centre Block is the large South Bank Orrery which proved a great attraction at the Festival of Britain Exhibition in 1951. The fluorescent planets are in a darkened room illuminated by ultra-violet light, and appear to float round the Sun. The diameter of Pluto's orbit is 16 feet.

Radio-astronomy, which has not yet found a place in the collections, will be represented in the new display, but rocketry,

space-flight and artificial satellites will be part of the aeronautics section on the top floor of the Centre Block.

The Common 3-foot reflecting telescope, which stands about 20-feet high, will be what the design experts call a vertical feature in the newly planned display. Dr A. A. Common made the telescope for the Science and Art Department about 1890 and it was lent to the Cambridge Solar Physics Observatory in 1913. It was used at Cambridge for more than forty years before it was replaced and returned to the Museum in 1954.

Finally it is hoped to have an observatory on the top of the new Centre Block. Many visitors inquire where there is a telescope through which they can look, and it will be useful to be able to satisfy this demand. A 20-foot rotating copper dome will house the Isaac Roberts telescope, which is at present in use at Herstmonceux. This twin-equatorial consists of a 20-inch reflector and a 7-inch refractor on opposite sides of the same equatorial mounting. It was built in 1885 by Sir Howard Grubb for Dr Isaac Roberts, F.R.S., who produced with it some excellent celestial photographs.

These are some of the ways in which the Museum will try to cater for the greatly increased interest in astronomy which has been awakened in the general public by the launching of artificial earth satellites and by the imminent prospect of space-flight.

Recent Advances in Astronomy

PATRICK MOORE

In the popular mind, the recent important advances in astronomy have been overshadowed by the spectacular achievements in space research. The attitude of the Press is partly responsible for this, even though the launching of a normal artificial satellite – or even a planetary probe – is no longer featured in the headlines, and is more generally relegated to a back page. Yet it must be remembered that advances in space research will lead on to immense benefits in the field of what we may term 'conventional' astronomy.

It may, therefore, be appropriate to refer here to the first true manned space-flights; by Major Yuri Gagarin of the U.S.S.R., and Commander Alan Shepard of the United States. Gagarin made a complete circuit of the Earth, and experienced conditions of zero gravity for a relatively prolonged period; Shepard's trip was more in the nature of a brief up-and-down 'hop'. One important fact is that both men landed safely, and suffered no ill-effects from their venture into space. Other flights have since been made.

The significance of these flights is that actual voyages to the Moon now appear to be probable in the foreseeable future, though not, of course, for some years yet. On the other hand it would be completely wrong to suggest that a Moon voyage is the only idea behind the space research programme. Manned flights form only one part of the programme – and probably not even the most important part. A 'soft landing' of an instrumented probe upon the lunar surface would be of more scientific value than an orbital flight by a man-carrying rocket moving at a few hundreds of miles above the surface of the Earth.

Such a 'soft landing' may be confidently expected soon; by the time these words appear in print, it may well have taken place. Meanwhile, let us turn from space research to some of the purely astronomical developments of 1960 and 1961.

Considerable attention has been focused on the planet Venus. It is true that the probe rocket launched toward it by the Russians, on February 12, 1961, was a partial success only, since its transmitter seems to have failed, and all contact with it was lost after less than three weeks; probably it passed within 70,000 miles of Venus in mid-May, but efforts to re-establish radio contact with it proved unsuccessful. However, the Soviet scientists announced some results in connexion with Venus itself, and gave a new value for the axial rotation period: ten days, with a possible error of one day either way, depending on the inclination of the planet's axis.

Up to now, efforts to measure the rotation period of Venus have met with failure. Many estimates have been made, ranging from 224·7 days (Dollfus, France), through about 30 days (Kuiper, U.S.A.) to only 22 hours 17 minutes (Kraus, U.S.A.). Various methods have been used; visual, photographic, spectroscopic and radio – but it could hardly be claimed that any of the results were reliable. The very long period, supported by Dollfus and other French astronomers, would indicate a 'captured' rotation, so that Venus would keep the same hemisphere turned permanently toward the Sun; however, it is not supported by temperature measurements, which show that both the dark and sunlit hemispheres are at about −39° C. (This refers, of course, to the upper atmosphere of the planet, since the true surface is permanently concealed.)

It is not yet clear how much reliance can be placed on the Soviet ten-day period. The method used was that of radar, and the measures are so difficult to make that there is bound to be considerable uncertainty. Further researches will, we may hope, shed some new light on this long-standing problem.

Radar methods have also been used to redetermine the astronomical unit, or distance between the Earth and the Sun. During late 1960 and early 1961, measures were made at Jodrell Bank and

in the U.S.A. and the U.S.S.R. The radar pulses were 'bounced' off Venus, and the 'echoes' received; since radar pulses travel at the same speed as visible light (186,000 miles per second) the time-lag between the transmission and the echo gives a perfect key to the distance of Venus. Once this is known, the distance of the Sun may be computed. Details are given in a note on another page.

In this connexion, it is worth remembering that a famous investigation into the length of the astronomical unit was made by Sir Harold Spencer Jones, the tenth Astronomer Royal. The recent death of Sir Harold came as a tragic shock to the scientific world as well as to his many friends. Since his retirement from the post of Astronomer Royal, following the completion of the major part of the transfer of the Royal Observatory from Greenwich to Herstmonceux, he had continued his active work, and was intimately concerned in the International Geophysical Year programme. As well as being an astronomer of the first rank, he was an able administrator, and a man who made friends wherever he went; his loss is deeply regretted not only in his own country, but also in all others.

A notable event of early 1961 was the total eclipse of the Sun, which occurred on February 15. From Britain the eclipse was partial only, and moreover the skies were generally cloudy, though a few areas were favoured by fine weather. Over the Continent, things were much better. The track of totality crossed south France, north Italy, Jugoslavia and south Russia, covering three major observatories – St Michel (France), Arcetri (Italy) and the Crimean Astrophysical Observatory.

Fortunately the conditions were good, and valuable results were obtained at all these stations. The general consensus of opinion seems to have been that this was the best total eclipse for many years – and it will remain the best European eclipse for a long time to come. An interesting sidelight was that the eclipse was shown on television. Using the Eurovision link, the B.B.C. transmitted pictures and commentaries from St Michel, Florence, and Mount Jastrebac in Jugoslavia, so that totality was shown three times. From the point of view of television techniques, the

programme was well worth attempting, and some useful information was gained in this direction.

One interesting piece of research was carried out by N. Kozirev in the Crimea. Throughout totality he concentrated upon taking spectrograms of the planet Mercury in an attempt to confirm the existence of an atmosphere, first reported by Dollfus some years ago to have a ground density of about 1/300 of that of the terrestrial atmosphere at sea-level. Normally, Mercury can never be seen against even a reasonably dark sky except when it is very low down; observations of it have therefore to be made in broad daylight, which complicates matters considerably. During totality, the sky became relatively dark, and Mercury was excellently placed for study. Kozirev's results have yet to be announced, but they will be of considerable value even if they prove to be wholly negative.

Mars was at opposition in late 1960, but the distance was greater than in 1956 or 1958, though partial compensation was afforded by the fact that the declination was more northerly. Studies carried out by W. Sinton in America have indicated that the spectra of the dark patches on the planet contain lines due to organic molecules. This does not, of course, prove that the patches are due to vegetation, but it certainly lends support to an already plausible theory. It is probably true to say that most astronomers now support the idea that the dark areas are due to living organisms, though there are some dissentients – notably W. McLaughlin (U.S.A.) who attributes them to volcanic ash, and V. Davidov (U.S.S.R.) who has put forward the theory that Mars is covered with ice, and has an underground hydrosphere. On the other hand, the fascinating hypothesis that the planet may support intelligent life has been universally rejected.

Bright comets have been rare in recent years; even the two comets of 1957, Arend-Roland and Mrkos, were very minor compared with the spectacular visitors of the past. In the spring of 1960 another naked-eye comet, Burnham's, was seen. Like the 1957 comets it was in the northern part of the sky, but unfortunately it proved to be something of a disappointment, and was

none too easy to see without binoculars or telescopic aid. No 'great' comets have been seen now since 1910. By the law of averages, another is certainly overdue; but we cannot tell when and where it will appear.

It is misleading to place undue emphasis on the Solar System, which represents, after all, a very insignificant part of the universe. To carry out studies of the stars and star-systems, powerful instruments are needed if adequate results are to be obtained; such instruments are beyond the means of the average amateur. In 1960 the new 102-inch reflector of the Crimean Astrophysical Observatory was brought into use, and the construction of the 236-inch to be erected in Siberia was well under way. Work has also been recommenced on the 98-inch Isaac Newton reflector which is to be set up at Herstmonceux, but much remains to be done before the telescope is anywhere near completion. This also applies to the large radio telescope, of 'dish' type, being built in the United States, and meanwhile the 250-foot paraboloid at Jodrell Bank remains the most powerful in the world. It is indeed fitting that the name of the leader of the Jodrell Bank team, Professor Sir Bernard Lovell, should have been included in the 1960 Honours List.

Considerable interest was aroused in 1960 by the measurement, by J. Minkowski in the United States, of the most remote galaxy so far known. The object (or possibly objects; it may be compound) lies in Boötes, and is known officially as 3C-295. Even on photographs taken with the Palomar 200-inch reflector it appears as nothing more than a blurred patch, but the spectrograms show that it lies at a distance of roughly 5,000–6,000 million light-years, and is receding at a speed of approximately 90,000 miles per second. This is equivalent to nearly half the speed of light.

Of course, one cannot be too precise; it is not many years since the revision of the cepheid scale led astronomers to double the size of the entire universe – and there may be further errors so far unsuspected. It seems, however, that the values given for 3C-295 are at least of the right order. It may well be that we are approaching the limit for optical telescopes based on the Earth, but radio

telescopes can probe further, though with less resolution; and radio astronomy gives us our best means of tackling the fascinating problem of how the universe began.

It is well known that there are two rival theories, the evolutionary and the steady-state. On the first, the material in the universe was once contained in what is known as the 'primeval atom'; this primeval atom exploded, and, after a complex sequence of events, led to the present state of affairs, with every group of galaxies receding from every other group. On the steady-state theory, the universe has always existed, and new matter is being continuously created out of nothingness, so that the distribution of the galaxies has always been much the same as it is now.

Radio results announced in 1960 by M. Ryle seemed to favour the evolutionary theory rather than the steady-state, and led to some controversy. The problem is dealt with, in slightly more detail, in a separate article; but it is important to remember that all present analyses are decidedly tentative, and it is premature to come to any definite conclusions.

These are only a few of the developments which have taken place within the last year or so, but perhaps enough has been said to show that astronomical science is anything but static; important advances are being made regularly. What the future holds for us, only time will tell.

Some Recommended Books

General:

Larousse Encyclopedia of Astronomy, by L. Rudaux and G. de Vaucouleurs. (Batchworth, 1959; 63*s.*).
Not an encyclopedia, but a detailed account of astronomy for beginners; 500 pages, and more than 800 diagrams and plates. Value for money.

Elementary Astronomy, by Otto Struve. (Oxford University Press, 1959; 55*s.*). A lavishly illustrated and well-produced book for the reader who does not mind a bit of mathematics.

Astronomy, by Robert H. Baker. (van Nostrand, 1959; $6.95). A standard text-book, which has now reached its 7th edition.

Astronomy, by T. G. Mehlin. (Chapman & Hall, 1959; 64*s.*). A college text-book with some new ideas.

Introduction to Astronomy, by Cecilia Payne-Gaposchkin. (Eyre & Spottiswoode, 1956; 50*s.*). Excellent general account of astronomy.

Astronomy for Entertainment, by Y. Perelman. (Central Books, 1958; 7*s.* 6*d.*). An unusual elementary account of some aspects of astronomy, translated from the Russian.

Atlas of the Universe, by B. Ernst and T. E. de Vries. (Nelson, 1961; 42*s.*). A detailed and profusely illustrated encyclopaedia of astronomy.

Lectures and Essays:

The Nature of the Universe, by F. Hoyle. (Blackwells, 1960; 8*s.* 6*d.*). A second and revised edition of the controversial broadcast talks of 1950.

Changing Views of the Universe, by Colin A. Ronan. (Eyre & Spottiswoode, 1960; 15*s.*) A study of the historical background.

Rival Theories of Cosmology, by H. Bondi, W. B. Bonnor and R. A. Lyttleton. (Oxford University Press, 1960; 9*s.* 6*d.*). A Third Programme discussion under the Chairmanship of Dr G. J. Whitrow.

The Individual and the Universe, by A. C. B. Lovell. (Oxford University Press, 1959; 10*s.* 6*d.*). The B.B.C. Reith Lectures, 1958.

The Modern Universe, by R. A. Lyttleton. (Grey Arrow Books, 1960; paper edition 3*s.* 6*d.*). A cheap reprint of the TV talks.

Radio Astronomy:

Radio Astronomy, by F. Graham Smith. (Penguin, 1960; 7*s.* 6*d.*). An excellent account by one of the Cambridge team.

Radio Studies of the Universe, by R. D. Davies and H. P. Palmer. (Routledge & Kegan Paul, 1959; 25*s.*). Two members of the Jodrell Bank team explain their work.

The Solar System:

The Planet Earth, Ed. D. R. Bates. (Pergamon Press, 1957; 35*s.*). A comprehensive account of geophysics and other earth-sciences by a number of authorities.

The Planet Jupiter, by B. M. Peek. (Faber & Faber, 1958; 42*s.*) .The only detailed account – and an excellent one – of this great planet.

Our Sun, by D. H. Menzel. (Harvard Books, Blakiston, 1959; $7.50.). Second edition of a well-known book.

The Face of the Sun, by H. W. Newton. (Penguin, 1958; 3*s.* 6*d.*). Full of information.

The Sun and its Influence, by M. A. Ellison. (Routledge & Kegan Paul, 1959; 25*s.*). Second edition of a very useful book.

The Sun, by A. Severny. (Lawrence & Wishart, 1959; 5*s*.). Translation of a work by a Russian astronomer.

Structure of the Moon's Surface, by G. Fielder. (Pergamon Press, 1961; 50*s*.). A detailed account of lunar science, unreservedly recommended to all those who are interested in the Moon.

Surface of the Moon, by V. A. Firsoff (Hutchinson, 1961; 21*s*.). The application of geological principles to lunar study.

Space Research:

Cosmic Rays, by G. Zhdanov. (Lawrence & Wishart, 1959; 4*s*. 6*d*.). A paper-back translation of a Russian text.

Satellites and Scientific Research, by D. King-Hele. (Routledge & Kegan Paul, 1960; 21*s*.). One of the best accounts so far of the behaviour and uses of artificial satellites.

Astronomical Societies

The advantages of joining an astronomical society are obvious, and this is a step which should be taken by any amateur who is even moderately interested in the subject. The leading society in Britain is of course the Royal Astronomical Society (Burlington House, Piccadilly, London, W.1) which is a professional organization, though there are many Fellows who are amateurs. The leading amateur society is the British Astronomical Association: secretarial address 303 Bath Road, Hounslow West, Middlesex. Meetings are held on the last Wednesday of each month (except July, August and September) at Burlington House, at 5 p.m. The annual subscription is 45*s.*; for a member 25 years of age or less on his last birthday preceding 1 August, the subscription is 30*s.* Special sections are devoted to the Sun, Moon, Mercury and Venus, Mars, Jupiter, Saturn, comets, meteors, variable stars, and aurorae and the Zodical Light; there is also a Historical Section, and a section dealing with instruments and observing methods. The B.A.A., founded in 1890, has a distinguished observing record. Publications include a regular *Journal* and annual *Handbook*.

For young enthusiasts there is the Junior Astronomical Society (secretarial address, 9 Hill View Road, Basingstoke, Hampshire) which caters mainly, though not exclusively, for those of school age. Meetings in London are held quarterly at Caxton Hall, near Victoria. The journal, *Hermes*, is issued quarterly. The annual subscription is 10*s.* There are various branches which organize their own programmes: at Croydon (J. H. Lytheer, 1 Temple Avenue, Shirley, Croydon, Surrey); Leeds (D. Fry, 5 Belle Vue Terrace, Belle Vue Road, Leeds 3); Golders Green (Miss L. Morrison, 49 Booth Road, Colindale, London, N.W.9); and Eastbourne (C. Oliver, 33 Commercial Road, Eastbourne, Sussex).

Other branches are in the process of formation. Inquiries should in the first instance be sent to the Society's Secretary, E. W. Turner.

Many towns have their own local astronomical societies. Among these are:

Name	*Secretarial Address*	*Member-ship*	*Annual Subscription*	*Meetings*	*Remarks*
Birmingham Astronomy Group	17 Hannafore Road, Edgbaston, Birmingham 16 (W. E. Marsh)	120	10*s* (5*s* for those under 21)	Monthly, Oct.–May at Midland Institute, Paradise Street, Birmingham	1
Bristol Astronomical Society	12 Lambley Road, Bristol 5 (S. J. Williams)	60	1 guinea (10*s* 6*d* for those under 16)	Monthly, Sept.–May, at Royal Fort, University of Bristol	
Chester Society of Natural Science: Dept. of Astronomy	15 Sheldon Avenue, Chester (Miss N. Thomas)	24	10*s* (6*s* for those under 21)	Grosvenor Museum, Grosvenor Street, Chester	2
Chesterfield Astronomical Society	10 George Street, Brimington, Chesterfield	80	15*s*	The Barnett Observatory	3
Crewe Astronomical Society	465 Crewe Road, Wistaston, Crewe, Coventry	60	12*s* 6*d*	Crewe County Grammar School, Ruskin Road, Crewe	
Cumberland and Westmorland Astronomical Society	55 North View, Aspatria, Cumberland, (W. L. Rae)				
Astronomical Society of Edinburgh	126 West Savile Terrace, Edinburgh 9	130	20*s*	Calton Hill Observatory	4
Fellowship of Junior Astronomers, Edinburgh	58 Ogilvie Terrace, Edinburgh 11	30	7*s* 6*d*	Calton Hill Observatory	5
Leeds Astronomical Society	The University, Leeds	120	10*s*	Leeds University, 2nd Wednesday of each month, October–March	
Leicester Astronomical Society	49 Bringhurst Road, Leicester (C. Shuttlewood)	60	1 guinea (10*s* for those aged 16–18; 5*s* for those under 16)	Leicester Museum and Art Gallery	6
Lincoln Astronomical Society	Oak Crescent, Cherry Willingham, Lincoln (P. Hammerton)	80	10*s* senior 5*s* junior	Lincoln Y.M.C.A.	7
Liverpool Astronomical Society	83 Moscow Drive, Liverpool 13 (L. Geoghegan)	200	12*s* 6*d* (4*s* for those under 21)	Royal Institution, Colquitt Street, Liverpool	8
Manchester University Astronomical Society	Dept. of Astronomy, The University, Manchester 13	85	3*s*	The University	9

Name	*Secretarial Address*	*Member-ship*	*Annual Subscription*	*Meetings*	*Remarks*
Manchester Astronomical Society	Craigside, facing Craig Avenue, Summerseat, Bury	150	£1 (seniors) 10*s* (juniors)	Godlee Observatory Manchester College of Technology, Sackville Street, Manchester, 1	10
Nottingham Astronomical Society	61 Abbey Road, Beeston, Notts (Miss M. Mott)	30	1 guinea	Nottingham Mechanics Institute; first Thursday in each month	11
Norwich Astronomical Society	68 Clarendon Road, Norwich (W. E. Bennett)	60	15*s* (7*s* 6*d* for those under 17)	Assembly House, Norwich, and the Observatory	12
Swansea Astronomical Society	77 Graiglwyd Road, Cockett, Swansea (R. E. Roberts)	25	1 guinea	Royal Institution of South Wales, Swansea	13
Torbay Astronomical Society	Bluehaze, Clennon Park, Paignton, Devon (Mrs A. Longman)	30	15*s*	R.A.F. Training Centre Newton Abbot, Devon; third Thursday of each month	
Warwickshire Astronomical Society	186 Rotherham Road, Coventry	25	5 guineas	20 Humber Road, Stoke, Coventry	14
York Astronomical Society	27 Garden Flat Lane, Dunnington, York	30	£1 (students 5*s*)	York Educational Settlement	15

Remarks

1. The Group has a 12 in. reflector in an observatory at Birmingham, and a 21 in. is under construction. General meetings are held once a month from October to May, with lectures and film shows. The Construction Section meets weekly throughout the year. The Group runs a lending library, an observing section, and a junior section.

2. From January to May a course of lectures is held in conjunction with the Liverpool University extra-mural department, on subjects allied to astronomy. Open to non-members of the Society. Fee 7*s*. 6*d*.

3. The Observatory has an 18 in. Newtonian reflector and also a lecture room.

4. Facilities are available to members at the Observatory, Calton Hill. Small telescopes are also loaned to members of the Observing Sections. Members meet on Fridays throughout the year at the Observatory. Library, and a collection of lantern slides. Monthly star maps and astronomy notes are issued to all members.

5. There are observing nights at the Observatory, Calton Hill.

Monthly notes are issued to members. Some small telescopes are loaned to members. Training is given in observing techniques. There is a small library.

6. The Observatory, with a 15 in. reflector, will be completed in 1962.

7. An observatory and lecture room are now being built.

8. The Society, founded in 1881, has a strong junior section, a radio physics section, a library and a collection of lantern slides. Telescopes are available for borrowing by members, and the Society's 5 in. Cooke equatorial is available to members at a weekly meeting held at the Society's Observatory, Central Technical College, Byrom Street, Liverpool.

9. The Society has the use of the Godlee Observatory, operated by the Manchester Astronomical Society. The Society also has facilities for producing telescope objectives, etc.

10. The Society's 12 in. and 8 in. reflectors are available two nights per week at least. Winter session lectures are held in the Reynolds Hall of the College.

11. The 8·5 in. Society reflector is kept by the Director of Observing, A. W. Lane Hall.

12. The Society has its own observatory, with a 10 in. reflector, and adjoining club-room, off Newmarket Road, Norwich. This is available to members at any time by arrangements. Regular evenings are Tuesdays, Wednesdays, and Saturdays.

13. The Swansea Observatory has a 9 in. Newtonian reflector, and photographic equipment.

14. Workshops contain grinding and polishing facilities. The Library and Club Room, available seven days a week, are available to all members. There is a monthly magazine, *Cosmos*.

15. Meetings are held at 7.30 on the second Thursday of each month.

Glossary of Astronomical Terms

aberration—(1) the distortion of an image in an imperfect optical system; (2) the apparent displacement of a star from its true position owing to the finite velocity of light. It includes (*a*) the effect of light-time, the object being seen where it was when light left it; this effect is ignored in dealing with stars, since the light-time is not known; (*b*) the effect of the Earth's motion, which, combined with the velocity of light, causes an apparent displacement of the object. This effect is called *stellar aberration*, and the combination of the two effects is *planetary aberration*.

absorption lines—dark lines in a continuous spectrum caused by absorption of light of certain wave-lengths by a layer of gas (e.g., an atmosphere) cooler than the source of light.

albedo—('whiteness')—the ratio of the amount of sunlight reflected from a planet or satellite to the amount received. The Moon reflects only 7 per cent of the sunlight falling on it; its albedo is therefore 0.07.

altitude—the angular distance of a body above the true horizon; the nature of the visible horizon will affect the apparent altitude.

angstrom unit—the unit of wave-length in measurements of light, X-rays, etc. Symbol A; it is one hundred-millionth part of a centimetre, or a ten-thousandth part of a micron. The whole of visible light is contained in the range from 3,900A (violet) to 7,500 A (red).

aphelion—that point in an (elliptical) orbit of a planet or comet which is farthest from the Sun.

apogee—that point in the orbit of the Moon, or of an artificial satellite, which is farthest from the centre of the Earth.

apparent place—the observed position of a star or planet, as distinct from the mean place.

apparent solar time—time measured by the hour angle of the true Sun; the time measured by a sundial. The difference apparent time *minus* mean time is the *equation of time*, and this may amount to more than 16 minutes in November.

appulse—a very close conjunction of two planets, or of a planet and a star.

apse line, or *line of apsides*—the line in an orbit which joins the nearest and farthest points from the central body; in an unperturbed ellipse it corresponds to the major axis.

asteroids—see *minor planets*.

Astronomical Ephemeris—the modern name (since 1960) of the British *Nautical Almanac*, which was first published in 1776; it is identical in content with the *American Ephemeris*.

astronomical unit—the mean distance of the Earth from the Sun; the semi-major axis of the Earth's orbit. May be taken as 93 million miles.

astrophysics—the branch of astronomy which uses the laws of physics to study the constitution and evolution of the stars.

azimuth—the angular bearing of an object measured round the horizon from north or south points. In astronomy it is now usual to measure the azimuth from the north round through east, south and west, from 0° to 360°.

binary—a double star in which the two components are physically connected, revolving about their common centre of mass under the influence of the mutual gravitational forces. Probably one star in every two or three is a binary.

celestial sphere—an imaginary sphere of infinite radius, centred at the observer, on which the stars and planets appear to be fixed.

Their positions may then be referred to fixed great circles (such as the equator or ecliptic) on the sphere.

cepheid—a variable star characterized by a rapid rise to maximum brightness, followed by a slower and less regular decline; named after the typical star Delta Cephei. The periods range from 1 to 45 days, and the period is in all cases proportional to the absolute brightness, from which distances can be measured.

chromosphere—the lower layer of the Sun's atmosphere, red in colour, and consisting mainly of hydrogen; it extends for some thousands of miles, while prominences rise from it to much greater distances.

circumpolar stars—stars which do not rise or set, but merely circle the pole; all stars whose declinations are greater than the colatitude of the observer are circumpolar.

cluster variables—short period variable stars first detected in globular clusters, and having periods less than one day.

clusters—groups of stars having a common motion through space. The main groups are (1) open clusters within the Galaxy containing at most a few hundred stars with dust and gas clouds; (2) globular clusters of a symmetrical shape, containing many thousands of stars including short-period variables and Population II stars. They are distributed uniformly at great distances round the centre of the Galaxy.

colatitude—the complement of the latitude; 90° minus the latitude. The meridian altitude of the equator at any place is equal to the colatitude.

colour index—the difference between the photographic and visual magnitudes of a star; from this value the effective temperature may be deduced.

comes—the fainter component of a double star.

conjunction—the nearest apparent approach of two celestial objects, when one appears to pass the other; usually considered to occur when they have the same longitude.

Inferior conjunction of Mercury and Venus occurs when the planet is between the Sun and the Earth.

Superior conjunction of any planet occurs when it is on the farther side of its orbit, the Sun lying between planet and Earth.

continuous creation—the theory that matter is being continuously created throughout the universe, to replace losses caused by the recession of the galaxies. This is the *steady-state* theory, and it implies that the universe had no beginning and will have no end; creation is confined to individual systems.

corona (*solar*)—a pearly-white halo of light surrounding the Sun; this is the outer layer of the Sun's atmosphere, and can be traced to great distances from the Sun, joining up with the zodiacal light.

cosmic radiation—highly penetrating radiation which reaches the Earth from outer space; it consists of electrically charged particles of high energy.

cosmogony—the science which deals with the origin of the universe, or of our Galaxy or the solar system.

cosmology—the study of the universe as a whole, its nature in space and time, and the relations between its various parts.

cusps—the horns of the moon or of an inferior planet when in the crescent phase.

D-layer—the lowest ionized layer in the Earth's atmosphere; it is about 50–60 miles above the Earth, and disappears almost completely at night.

day—the period of the Earth's rotation. It may be measured with respect to the stars (*sidereal day*), the true sun (*apparent solar day*) or the mean sun (*mean solar day*). See *apparent solar time, Greenwich Mean Time, mean solar time, sidereal day.*

declination—the angular distance of a celestial object north (+) or south (−) of the celestial equator.

dew cap—an open tube fitted to a refractor, extending the telescope tube beyond the objective; it prevents condensation on the front surface of the lens.

diffraction rings—the image of a star in a telescope is not a point, but has a definite size; this 'spurious disc' is surrounded by a number of diffraction rings. These are caused by the spreading of light (which is a wave-motion) round the edges of an obstacle —in this case, the aperture of the telescope—to give alternate light and dark bands called diffraction fringes. If the aperture of the telescope is increased, the spurious disc becomes smaller, and the diffraction rings less conspicuous.

Doppler effect—the apparent change of wave-length in any form of wave-motion (sound, light, radio, etc.) caused by the motion of the observer or of the source, or both. The change is proportional to the velocity.

double stars—two stars which appear close together in the sky, either because they are physically connected (see *binary*) or because they chance to be almost in line, though at different distances (optical double).

dwarf stars—the stars of the *main sequence*; the giant stars are more luminous, and the white dwarfs less luminous, than the stars of the main sequence.

eclipse—an eclipse of the Moon (or any other satellite) occurs when it passes into the shadow of the planet; such an eclipse may be *penumbral* if the satellite does not enter the unbra of the shadow, or *partial* or *total*. An eclipse of the Sun occurs when the Moon passes between the observer and the Sun; in this case the eclipse may be *partial, annular* (ring-like, if the Moon does not entirely cover the Sun's surface) or *total*. An eclipse of the Sun can only occur at New Moon, and an eclipse of the Moon only at Full Moon.

ecliptic—the great circle on the celestial sphere which marks the apparent path of the Sun. It is the projection of the Earth's orbit on the celestial sphere.

elongation—the apparent angular distance of a planet from the Sun, or of a satellite from the parent planet, etc.

emission lines—bright lines in a spectrum due to the emission of light from a glowing gas at low pressure.

ephemeris—a table of positions of the Sun, Moon, planets, comets, etc., for given dates at regular intervals.

epoch—a date chosen for reference purposes in quoting astronomical data which vary with time, e.g., the position of the equinox, or the elements of an orbit, are always quoted for a certain epoch.

equator—the celestial equator is the great circle on the celestial sphere which is the projection of the terrestial equator.

equatorial—a telescope arranged to revolve about an axis parallel to the Earth's axis, so that as it turns it will keep a star constantly in the field of view as it moves from east to west across the sky.

equinox—one of the points of intersection of the equator and ecliptic; also the times at which the Sun passes through these points, the vernal equinox occurring on 20 or 21 March, the autumnal equinox on 23 September. The vernal equinox or First Point of Aries is the origin from which right ascension and longitude are measured.

escape velocity—the least velocity which an object must acquire, at a given distance from a centre of attraction (e.g., Sun or planet), in order to escape from the gravitational field of the attracting body in a parabolic orbit. This parabolic velocity depends on the distance, and is 1·414 times the velocity in a circular orbit at that distance.

evening star—(1) the planets Mercury or Venus when seen in the western sky at sunset; (2) also used more loosely to describe any planet which (after opposition) transits before midnight.

expansion of the universe—the recession of the extra-galactic nebulae, at rates which are proportional to their distances, is taken as evidence that the universe is continuously expanding. See *red shift*, *Hubble's constant*.

extra-galactic nebulae—the nebulae that lie outside our Galaxy; they are themselves galaxies, and tend to form clusters.

First Point of Aries—see *equinox*.

flares (solar)—brief but very bright outbursts of hydrogen, seen on the Sun, usually in the neighbourhood of sunspots; often cause radio fade-outs and magnetic disturbances on Earth.

flare stars—stars whose spectra show outbursts of light of a similar nature to solar flares, but on a much greater scale.

free fall—the normal state of motion in an orbit in space under the gravitational attraction of a central body. In free fall, the vehicle is not driven, and everything within it is in a state of zero gravity.

frequency—the number of waves passing a given point every second. The product of frequency and wave length gives the velocity of the waves.

galaxies—the name now used for the extra-galactic nebulae; it is estimated that 10,000 million galaxies are observable.

Galaxy—(1) the Milky Way; (2) the entire system of gas, dust and stars, of which the Sun is one; it is now known to have a spiral structure.

gauss—the unit in which the intensity of a magnetic field is measured. The Earth's magnetic field varies over the surface from about 0·3 to 0·6 gauss.

gegenschein—a faint glow in the sky sometime seen on the ecliptic opposite the Sun. It appears to be connected with the zodiacal light, and is sometimes called the counterglow.

Geiger counter—a gas-filled tube which permits an electric charge to pass through it when the gas is ionized; used for counting the number of charged particles that enter it.

geocentric—having the centre of the Earth as origin or as viewpoint.

giant stars—stars which are more luminous (and therefore have a greater surface and size) than the main sequence stars of the same spectral type.

great circle—a circle on the celestial sphere which divides the sphere into two equal hemispheres, e.g., the horizon, the

equator, the ecliptic. The shortest distance between two points on the celestial sphere is an arc of a great circle.

Greenwich Mean Time (G.M.T.)—mean solar time, measured from the meridian of Greenwich and reckoned through 24 hours from Greenwich midnight; it is identical with Universal Time.

Hα (hydrogen alpha)—one of the lines of the hydrogen spectrum; it is prominent in the spectrum of the Sun (at 6563 A) and gives the red colour to the chromosphere and prominences.

harvest moon—in the northern hemisphere the Full Moon which occurs nearest to the autumnal equinox, when the Moon rises on successive nights at about the same time. The same phenomenon occurs in spring in the southern hemisphere.

heliocentric—having the Sun as origin; viewed from the centre of the Sun.

horizon—the great circle on the celestial sphere which is everywhere 90° from the zenith; the observed horizon will differ from this because of obstructions or the height of the observer.

hour angle—the angular distance of a celestial body from the meridian, measured along the equator westwards in hours minutes and seconds; it is found by subtracting the right ascension of the body from the local sidereal time.

Hubble's constant—the factor of proportionality in Hubble's Law connecting the velocity of recession of the galaxies with their distance. Recent work suggests a value of 55 km/sec per million light-years, and this leads to a figure of about 6,000 million years since the recession began, i.e., when the galaxies were almost in contact. See *expansion of the universe*.

Hunter's Moon—the Full Moon following the harvest moon, at which time conditions are often very similar.

hydrogen I and II—the hydrogen of interstellar space is either neutral atomic hydrogen (hydrogen I), or ionized hydrogen (hydrogen II). Hydrogen I is observable only by means of the

21 centimetre radio line; hydrogen II is found in the neighbourhood of very hot stars, and is readily photographed.

inferior planets—Mercury and Venus, which are inferior in the sense of revolving in orbits smaller than the Earth's.

inner planets—the planets Mercury to Mars; a loose term used to distinguish them from the outer planets, which lie at much greater distances from the Sun.

interferometer—an instrument for making very small measurements by utilizing interference fringes. Two rays of light travelling along different paths from the same source may reinforce or cancel each other, so producing alternate light and dark bands, the distance between which is a measure of the difference in the two paths of the light rays. The optical interferometer has been used for measuring the diameters of some supergiant stars; similar principles are used in the interferometers used in radio astronomy.

interplanetary matter—a term which may be used to include comets, meteoric dust, cosmic rays, dust, electrons, etc., and which emphasizes the fact that space is not empty.

interstellar hydrogen—the commonest element in the universe—see hydrogen I and II.

ionization—the production of electrically charged particles from a neutral atom or molecule. In astronomy the ions of the metals, and of hydrogen and other gases are of the most frequent reference; these are ionized by the loss of electrons, producing positively charged ions.

ionosphere—the upper region of the Earth's atmosphere, in which the gases are largely ionized. Several layers (F-layer, E-layer, D-layer) are recognized, and these have the property of reflecting radio-waves, so making long-distance short-wave communication possible.

island universes—an old term for the extra-galactic nebulae.

isophotes—lines which connect points of equal light intensity on a

graph or chart; the effect is to produce a kind of contour map which indicates levels of brightness.

kiloparsec—a thousand parsecs; about 3,260 light-years.

latitude—(1) on Earth, the angular distance north or south of the equator; (2) celestial latitude is the angular distance north (+) or south (−) of the ecliptic.

librations—apparent oscillations of the Moon on its axis, due to the inclination of the orbit of the Moon, and to its varying velocity. The term is also used of other forms of oscillation of planets or satellites.

light-time—the time taken by light to travel from a celestial object to the observer. This may vary from a little more than a second in the case of the Moon, to many thousands of millions of years in the case of some of the distant galaxies.

light-year—the distance that light travels in a year at a speed of 186,000 miles a second. It amounts to 5,880,000,000,000 miles or 63,240 astronomical units. The nearest known star (Proxima Centauri) is at a distance of 4·3 light years.

line of sight velocity—see *radial velocity*.

local group—a cluster comprising nearly a score of galaxies, of which our Galaxy is one; the group also includes the Andromeda nebula and the Magellanic clouds.

longitude—(1) on Earth, the angular distance east or west of the meridian of Greenwich; (2) celestial longitude is the angular distance, measured along the ecliptic from 0° to 360°, eastwards from the equinox.

luminosity—the actual output of light of a star, as opposed to the apparent brightness measured on Earth by an observer.

Lyman alpha—the first (longest wavelength) of a series of lines in the ultra-violet spectrum of hydrogen.

Lyot filter—a light filter used in viewing the Sun; it allows the passage of light of a very restricted wave-length band (usually that of Hα) and permits direct observation of the sun's chromosphere.

M = *Messier*. An abbreviation applied to the number of a nebula in Messier's catalogue.

Magellanic clouds—two large irregular nebulae visible to the naked eye in the southern hemisphere; these are the two nearest galaxies.

magnetic field—the entire space in which magnetic forces can be detected; apart from the Earth's magnetic fields, there are known to be strong magnetic fields associated with sunspots and certain stars, and there is believed to be a magnetic field in interstellar space.

magnetic storms—large scale disturbances in the Earth's magnetic field, associated with solar activity; usually accompanied by displays of aurorae and the disruption of radio and telegraphic communication.

magnitude—the measure of apparent brightness of a star or planet. The naked eye can appreciate stars down to magnitude 6, but the 200-inch telescope can photograph stars a little fainter than magnitude 22. A difference of one magnitude represents a ratio of brightness of 2·512; an increase of 5 magnitudes therefore indicates a hundred-fold decrease in brightness. *Absolute magnitude* is the magnitude a star would have if it were seen from a standard distance of 10 parsecs.

main sequence—if the stars are arranged in order of increasing absolute magnitude, the vast majority of them form a progressive sequence of decreasing temperature, size and brightness; this main sequence is best displayed on a graph of absolute magnitudes against spectral type, colour index or temperature. The Sun belongs to the main sequence.

mass spectrometer—an instrument for determining the masses of positively charged particles (e.g. metal ions) by measuring their displacement in a combined magnetic and electrostatic field.

mean place—the position of a star as given in a star catalogue is a mean place, referred to some particular epoch and equinox. The effects of precession, nutation, aberration and (where

appreciable) of parallax, proper motion and orbital motion have been removed; these can be re-calculated for any future date, and when added to the mean place give the apparent place for that date.

mean solar time—a uniform measure of time defined by the hour angle of the mean sun; see *G.M.T.*

mean sun—an imaginary body which moves round the celestial equator at a uniform speed equal to the average rate of motion of the true Sun round the ecliptic.

meridian—the great circle on the celestial sphere which passes through the poles and the zenith, intersecting the horizon at the north and south points. The term is generally used only of the upper meridian, i.e., that part of the meridian from the south point, up through the zenith to the pole.

meteor—a 'shooting star'; not a star, but a small particle which enters the Earth's atmosphere from outer space, and is destroyed by friction, leaving a luminous streak in the upper atmosphere; height 40 to 90 miles, speed 10 to 40 miles per second. The very bright meteors are called *fireballs*, or (if they explode) *bolides*. Most meteors are sporadic, but certain streams of meteoric dust are known, whose orbits about the Sun are intersected by the Earth each year. The resulting increase in the number of meteors, which will all come from some particular radiant, is known as a *meteor shower*. Meteors are also detected by radar methods and some daylight showers are of great interest.

meteorite—a solid body of iron or stone which falls on the Earth's surface from outer space; meteorites are thought to be of a different nature from the average meteor, and are probably derived from minor planets rather than comets.

Metonic cycle—a period of nineteen years, after which the whole cycle of phases of the Moon repeats on the same days of the year; named after the Greek astronomer Meton (*c.* 432 B.C.).

micrometeorites—fine dust of a meteoric origin, but too fine to be destroyed by friction in the atmosphere.

micron—a unit of length equal to one thousandth of a millimetre.

midnight sun—a popular term for the appearance of the Sun above the horizon all night in high latitudes; the phenomenon is visible at some period of the year from all places within the Arctic or Antarctic circles. The Moon and planets can, of course, display the same phenomenon.

Milky Way—the band of light extending round the sky, which is shown by the telescope to consist of countless faint stars; it represents our view of the Galaxy in which we are immersed.

minor planets—a swarm of small bodies, less than 500 miles in diameter, most of which revolve about the Sun between the orbits of Mars and Jupiter. About 1,600 have well-defined orbits, but their total number probably runs into hundreds of thousands. Also called *asteroids*.

month—the average period of revolution of the Moon about the Earth; it bears no relation to the calendar month. The length of the month depends on the point of reference; the more important are the *sidereal month*, referred to the stars, of 27·32 days, and the *synodical month*, referred to the Sun, and giving 29·53 days between similar phases. Owing to the variations in the Moon's orbit, the actual length of the month may vary considerably.

morning star—Mercury or Venus, when seen in the eastern sky before dawn. Also used as a loose description of any planet which transits after midnight (i.e., before opposition).

Nautical Almanac—the navigational ephemeris, giving astronomical information in a form suitable for use by navigators.

nebulae—originally the term referred to any hazy patch of light among the stars; it is now restricted to the gaseous nebulae (either bright or dark) which are found in or near the Milky Way, and are irregular in outline. The extra-galactic nebulae, more regular in shape, show the spectrum of starlight, and are galaxies (spiral, elliptical, etc.); they are found in all parts of the sky.

neutrons—the neutral particles which, together with protons, form the nuclei of atoms.

node—the point at which the orbit of a planet, comet, satellite, etc., intersects the ecliptic (or other great circle of reference).

nova—a star which appears suddenly in the sky. Sometimes called 'new' or 'temporary' stars, but the appearance is due to an intense outburst of light from the surface of an unstable star. A score or more appear every year in our Galaxy. See also *supernova*.

nucleus—the massive part of an atom, composed of protons and neutrons. The term is also applied to the denser parts of the head of a comet or other luminous object.

nutation—a nodding of the Earth's axis; a small irregular oscillation of the pole about its mean position, and therefore additional to the slow uniform motion of precession.

obliquity of the ecliptic—the angle between the equator and the ecliptic; may be regarded as the angle at which the Earth's axis is tilted.

occultation—the disappearance of a star (or other body) by the passage in front of it of a nearer body of larger apparent size. The most important occultations are those of stars, planets, and radio sources by the Moon.

opposition—a superior planet is at opposition when its longitude differs from that of the Sun by 180°.

outer planets—a term used for the planets Jupiter to Pluto.

parabolic velocity—see *escape velocity*.

parallax—the apparent change in the position of an object on the celestial sphere caused by a change in position of the observer. *Annual parallax* is the change in position of a star due to the annual motion of the Earth, and is the angle subtended by the radius of the Earth's orbit; generally called simply parallax. *Horizontal parallax* of the Moon or of a planet is the angle subtended at that body by the Earth's equatorial radius.

parsec—the distance at which the (annual) parallax of a star is

1 second of arc. It is a large unit, equal to 206,265 astronomical units, or 3·26 light-years.

penumbra—the outer diffuse region of the shadow of the Moon or of a planet, where some light is still received from the Sun; the term is also applied to the outer regions of a sunspot.

perigee—that point in the orbit of the Moon, or of an artificial satellite, which is nearest to the centre of the Earth.

perihelion—that point in an (elliptical) orbit in the solar system which is nearest to the Sun.

perturbations—disturbances in the regular orbital motion of a planet, comet, etc., caused by the gravitational attraction of other bodies.

phases—the changing shape of the illuminated part of the Moon (or of a planet or satellite) due to the relative positions of Sun, Moon and Earth. The Moon and the inferior planets show all the phases from *new* (when the body is invisible) through *crescent*, *quarter*, *gibbous* to *full*, decreasing through *gibbous*, *quarter* to *crescent* and *new* again. The superior planets and their satellites show only the full and gibbous phases.

photoelectric cell—an electronic device in which the incidence of light causes a change in an electric current.

photoelectric photometry—an important branch of modern photometry in which the photoelectric cell is used to measure stellar magnitudes, etc.

photographic zenith tube (P.Z.T.)—a fixed telescope directed to the zenith, used for photographing stars as they pass overhead for the exact determination of time.

photometry—the measurement of the apparent brightness of a distant source, such as a star, by comparison with that of a source of known intensity.

photomultiplier—a complex form of photoelectric cell, giving enormous amplification of the initial current.

photon—the smallest amount (or 'quantum') of light energy. It

may be thought of as a particle whose mass depends on the frequency, or as a short train of waves.

plage—bright hydrogen or calcium clouds that are observed near sunspots in the Sun's chromosphere; originally called 'bright flocculi'.

planet—a large, cold, solid body, moving in an elliptical orbit about the Sun, and shining solely by reflected sunlight. In addition to the nine major planets, many hundreds of minor planets are regularly observed.

polarization—the process by which light or radio waves are restricted to vibrations in one direction (or plane) only.

pole—the celestial poles are the points on the celestial sphere towards which the axis of the Earth is directed. The word is also used with reference to any great circle; the diameter of the sphere which is perpendicular to the great circle will intersect the sphere at two points called poles.

Populations I and II—a term used by Baade to distinguish two main types of stars. Population I contains the hot blue-white stars found in the arms of spiral galaxies; Population II stars are the older red stars found in the central regions of galaxies and in globular clusters, where dust and gas are absent.

position angle—the direction of one object from another; measured from the north point of the principal object through east from 0° to 360°.

precession—the slow twisting of the Earth's axis in space, the pole describing a circle round the pole of the ecliptic in a period of about 26,000 years. This does not alter the relative positions of the stars, but causes the equinox to move westwards round the ecliptic, so that the positions of the stars with respect to the equator (i.e., the R.A. and dec.) or the horizon change slowly with time.

primary focus—(prime focus)—the focal plane of the objective or main mirror of a telescope; the term indicates that the instrument is used without an eyepiece or any other lens or mirror.

profile, line—a tracing of the intensity of the image of an emission line; measured across the line it reveals the fine structure in detail.

proper motion—the motion of a star at right angles to the line of sight; the actual change of position of the star due to its real motion in space.

proton—the positively charged particle which forms the nucleus of the hydrogen atom. The nuclei of other atoms are composed of protons and neutrons.

pulsating stars—variable stars, both irregular and of the cepheid type. Such stars are believed to expand and contract, and are brightest when contracted. The behaviour is not, however, completely understood.

quadrature—the positions of two celestial bodies when their directions from the observer are at right angles; generally used of the Moon or a planet when at an elongation from the Sun of 90° or 270°.

radial velocity—the velocity of a star towards, or away from, the observer; measured by the Doppler effect in the star's spectrum.

radiant—the point (or small area) from which the tracks of the meteors in a meteor shower appear to originate. This is an effect of perspective (as in the case of railway lines), the paths of all the meteors in the shower being sensibly parallel.

radio astronomy—the study of radio waves received from the Sun, planets, interstellar hydrogen, and more distant galactic sources; also the use of radar methods in studying the Moon, planets, meteors, etc.

radius vector—the line joining any body revolving in an orbit to its centre of attraction, as the line joining a planet to the Sun.

red shift—the extra-galactic nebulae show a displacement of their spectral lines towards the red end of the spectrum. This is interpreted as a Doppler effect, indicating that all these galaxies are receding from us. See *expansion of the universe*.

reflector—a reflecting telescope, in which the initial image is formed by reflection from the upper surface of a spherical or parabolic mirror.

refractor—a refracting telescope, in which the image is formed by refraction through the main lens, called the object glass or objective.

refraction—the bending of a ray of light when it passes from one transparent medium to another.

resolving power—the ability of an optical instrument to show fine detail or to separate the images of very close objects; resolving power depends on the aperture of the instrument.

retrograde motion—(1) the apparent westerly motion of a planet among the stars caused by the easterly motion of the Earth; with a superior planet, opposition occurs about the mid-point of the retrogression. With the inferior planets, retrograde motion occurs at the time of inferior conjunction, and is not so readily observed. (2) True retrograde motion occurs in the orbits of comets and satellites which have inclinations greater than 90°.

revolution—orbital motion about a centre of attraction, as in the revolution of the Earth about the Sun.

right ascension—the angular distance of a body from the equinox, measured eastwards along the celestial equator, and usually expressed in hours, minutes and seconds up to 24 hours.

rotation—the turning of a body about its axis; thus the Earth rotates about its axis, but revolves about the Sun.

Saros—the eclipse cycle of 6,585·3 days (18 years and 10 or 11 days) after which Sun and Moon return to the same relative positions with respect to the Moon's node, and the entire series of eclipses repeat in the same order and under similar conditions. During one Saros there are about 70 eclipses, 41 of the Sun and 29 of the Moon.

Schmidt telescope—a reflector in which the surface of the main mirror is part of a sphere, and the resulting aberrations are

corrected by a thin glass correcting plate placed before the mirror.

semidiurnal arc—the angle (or the time) required by a celestial object to describe its apparent motion across the sky from rising to transit, or from transit to setting.

sidereal day—the interval between two successive transits of the same star; it is equal to $23^h\ 56^m\ 04^s{\cdot}09$ of mean solar time, and the difference from 24 hours causes the stars to rise and set 4 minutes earlier each day.

sidereal period—the period of a planet or comet measured with respect to the stars.

sidereal time—time measured by rotation of the Earth with respect to the stars. The sidereal time at any place is equal to the right ascension of an object on the meridian at that time.

solar motion—the motion of the Sun (with reference to the neighbouring stars) of about 12 miles per second towards the constellation Hercules; the term is also used of the Sun's share in the rotation of the Galaxy, which carries it towards the stars of Cygnus at about 130 miles per second.

Solar System—the Sun, with its family of planets, comets, meteors, dust and gas, all of which are controlled by the Sun's gravitational attraction and are influenced by its radiation.

solar parallax—the horizontal parallax of the Sun; it amounts to $8''{\cdot}79$, from which is derived the distance of the Earth from the Sun.

solstice—the place (or the time) at which the Sun reaches its greatest declination north (summer solstice) or south (winter solstice).

spectral types—the main types of stellar spectra, arranged in order of decreasing temperatures, are denoted by the letters O-B-A-F-G-K-M-R-N-S, each group being further subdivided by the use of small letters or of figures from 0 to 9. There is thus a progression from the hot blue-white helium stars, through the

hydrogen stars of type A to the stars of type G, like the Sun, in which numerous metallic lines are seen; the stars of later types become cooler and redder, and show absorption bands due to molecules such as titanium oxide and carbon compounds.

spectrograph—an instrument for photographing spectra.

spectroheliograph—an instrument for photographing the Sun in the light of one particular wave-length, giving, for example, the appearance of the hydrogen or calcium clouds of the chromosphere.

spectrohelioscope—an instrument for continuously viewing the Sun in the light of one wave-length.

spectroscopic binaries—binary stars which are so close together as to be invisible in the telescope, but which are so placed that their double spectra can be studied by means of the Doppler effect.

spectrum—the rainbow band of colours produced when white light from a small source is passed through a glass prism is really a series of overlapping images of the source, each different colour corresponding to a definite wave-length. Only an incandescent substance produces this continuous spectrum; a single element in the gaseous state produces a line spectrum, i.e., only certain wave-lengths are present, as coloured lines. The positions of these lines serves to identify the element. See also *emission lines*, *absorption lines*, *Doppler effect*.

star—a self-luminous globe of gas of the same general nature as the Sun, although it may differ in size and temperature, etc. There are probably a hundred thousand million stars in our Galaxy.

stationary point—a point in the apparent path of a planet at which it appears to be stationary in longitude (but may still be moving in latitude). Stationary points occur at the beginning and end of the period of retrograde motion, i.e., before and after opposition or inferior conjunction.

steady-state theory—see *continuous creation.*

Sun—a star of spectral type GO and absolute magnitude +5. It is a sphere of intensely hot gas, about 864,000 miles in diameter; the surface temperature is about 6,000°C but must rise to many millions of degrees in the interior. The visible surface is the *photosphere*, above which lie the *chromosphere* and the *corona.* The Sun rotates, in the same direction as the planets revolve, in about 25 days.

sunspot—a dark spot appearing on the Sun; the dark centre (the *umbra*) is surrounded by the lighter *penumbra*, but they only appear dark by contrast with the brilliant solar surface. A sunspot may be as much as 100,000 miles or more across.

sunspot cycle—the number of sunspots shows a marked tendency to maximum about every eleven years; there are considerable variations both in the numbers and the period.

supergiant stars—intensely luminous stars of low density and great size; their constitution and evolution appear to be different from that of ordinary stars.

superior planets—the planets from Mars to Pluto, which revolve in orbits larger than that of the Earth.

supernova—an exceptionally brilliant nova, rare in our Galaxy, but so brilliant that about 50 have been observed in other galaxies. The Crab nebula is the remains of a supernova explosion.

synchrotron—a machine for accelerating charged particles in a combined electrostatic and magnetic field. At very high energies, an electron beam produced in this way gives out a blue glow which is called synchrotron radiation.

synodic period—the time taken by a planet or satellite to return to the same relative positions with respect to the Sun and Earth; hence the interval between oppositions or conjunctions.

terminator—the line separating the dark and illuminated sides of a planet or satellite. The terminator on the Moon is quite

sharp, indicating the absence of any appreciable atmosphere; the Sun is rising on the terminator before Full Moon, and is setting on this line afterwards.

transit—the passage of any celestial body across the meridian; also used for the passage of a satellite or its shadow across the face of a planet, or of Mercury or Venus across the face of the Sun.

twilight—the illumination of earth and sky which lasts from sunset until darkness, and from darkness until sunrise; there would be no twilight in the absence of an atmosphere, as on the Moon. Theoretically, darkness begins and ends when the Sun is 18° below the horizon, but in this country in the summer months the Sun is not depressed to this extent, and there is a certain amount of twilight throughout the night.

umbra—the central dark part of the shadow of the Moon or of a planet, where no light is received from the Sun; also applied to the darker central region of a sunspot.

U.T.—universal time—see *G.M.T.*

variable stars—stars whose light varies because of some internal cause; the eclipsing binaries are also variable, but are generally treated as a separate class. *See cepheids, cluster-type variables, nova.*

wavelength—the distance between successive troughs or crests in a wave motion; the velocity of the wave is given by frequency multiplied by wavelength. See *angstrom unit.*

white dwarfs—very small faint stars of extraordinarily high density; the normal structure of the atoms in these stars has broken down, and they contain nuclei and electrons packed together as tightly as possible. Their masses are about the same as that of the Sun, but the density may rise to millions of times that of water. Such stars appear to be very common, but are faint and difficult to detect. The best known example is the companion of *Sirius.*

year—the period of the Earth's revolution about the Sun. Measured from equinox to equinox it amounts to 365·2422

days, and the civil calendar, with its rules for leap-years, is designed to allow for the extra decimal of a day.

Zeeman effect—the splitting of a spectrum line into a number of components when the source of light is subject to a strong magnetic field; it is observed in the spectra of sunspots.

zenith—the point on the celestial sphere which is directly overhead, as determined by a plumb-line.

zodiac—a belt of the sky about 8° wide on either side of the ecliptic, in which the Sun, Moon and major planets are always to be found.

zodiacal light—a faint luminous band of light along the ecliptic stretching outwards from the Sun; best seen after sunset or before sunrise. Its spectrum is that of reflected sunlight, and it appears to consist of small particles, forming an extension of the solar corona.

Some Interesting Telescopic Objects

The owner of a small telescope must not expect too much from his instrument. Those wonderful photographs of nebulæ which are used to illustrate text-books are taken with long exposures with large telescopes, and the photographic process can reveal far more than the eye can ever see. However, there is plenty to look for in the sky, and any instrument, however small, will show a great deal of the wonder and beauty of the universe around us.

A telescope is seldom satisfactory for the study of large clusters and groups of stars because the field of view is too small. A pair of binoculars is easier to handle, and will give magnificent views of open clusters such as the Pleiades, the colours of some of the more brilliant stars such as *Betelgeuse* and *Antares*, and the fascinating chains and lines of stars in many parts of the Milky Way, especially in Aquila, Cassiopeia, Cygnus, Lyra and Perseus.

In the following list, which makes no pretence of being complete, some of the more interesting telescopic objects are arranged in order of right ascension. They may all be found on a suitable star atlas, such as *Norton's Star Atlas* (Gall & Inglis), and positions have been given for the benefit of those observers who have telescopes equipped with setting circles.

ALPHA CASSIOPEIÆ (*Shedir*). R.A. $0^h\ 38^m{\cdot}3$, Dec. $+56°\ 20'$

A K-type star in the W. of Cassiopeia. It is an irregular variable, fluctuating between magnitude 2·1 and 2·7, though its normal magnitude is about 2·3. Generally speaking, the variations are very slow, and there is some doubt whether they are real. Beta Cassiopeiæ (magnitude 2·42) is a useful comparison star. The orange hue of *Shedir* is well brought out with binoculars.

MESSIER 31 ANDROMEDÆ. R.A. $0^h\ 40^m{\cdot}6$, Dec. $+41°\ 04'$

The Great Spiral, faintly visible to the naked eye not far from the 4th-magnitude star Nu Andromedæ. It is one of the closest of the external galaxies, and lies at a distance of about 2 million light-years. It must be admitted that in any small or moderate telescope it is a disappointing object, and photographs taken with large instruments are needed to show the spiral form adequately.

H.VIII. 78 CASSIOPEIÆ. R.A. $0^h\ 41^m{\cdot}2$, Dec. $+61°\ 35'$

A fine star-cluster, between Gamma and Kappa Cassiopeiæ. A small telescope will show it well.

GAMMA CASSIOPEIÆ. R.A. $0^h\ 54^m{\cdot}4$, Dec. $+60°\ 31'$

A most extraordinary star, with a spectrum which is classed as B0 (peculiar). It is regarded as a pseudo-nova, since it sometimes undergoes outbursts – for instance in 1936, when it rose to magnitude 1·6. Its normal magnitude is between 2·3 and 2·8. Useful comparison stars are Beta Cassiopeiæ (2·42) and Delta (2·80).

MESSIER 33 TRIANGULI. R.A. $1^h\ 31^m{\cdot}7$, Dec. $+30°\ 28'$

One of the closest of the external galaxies, and a member of the Local Group. Photographs reveal that it is a spiral. In moderate telescopes it is a faint and very difficult object.

GAMMA ARIETIS. R.A. $1^h\ 51^m{\cdot}4$, Dec. $+19°\ 06'$

An excellent double. Magnitudes 4·2, 4·4; position angle 000°; distance $8''{\cdot}4$. Any small telescope will show both components well. It is easy to locate, as it lies close to Beta Arietis.

ALPHA URSÆ MINORIS (*Polaris*). R.A. $1^h\ 57^m{\cdot}2$, Dec. $+89°\ 05'$

The Pole Star. It is of magnitude 2·0, but is actually a cepheid variable of small range. The spectrum is F8. It has a ninth-magnitude companion (p.a. 217°, distance $18''{\cdot}3$) visible with a 3-inch telescope; it is said to be visible even with a 2-inch.

GAMMA ANDROMEDÆ. R.A. $2^h\ 01^m{\cdot}6$, Dec. $+42°\ 09'$

A superb double. The primary is a K-type star of magnitude

2·3; the companion is of magnitude 5, and is bluish (p.a. 061°; distance 9″·7.) The companion is itself a close binary; distance 0″·5, period 55 years. The main pair forms a superb object in a moderate telescope.

H.VI 33–4 PERSEI. R.A. (*for* H.VI. 33) $2^h\ 16^m{\cdot}3$, Dec. +56° 59′

Twin clusters in the 'Sword-Handle' of Perseus; just visible to the naked eye. Each is about 45′ in diameter. Small telescopes will show them adequately; they form one of the most magnificent spectacles in the whole sky. Between the two clusters lies a reddish star.

OMICRON CETI (*Mira*). R.A. $2^h\ 17^m{\cdot}4$, Dec. −3° 09′

The famous variable star. It has an average period of 331 days, and its magnitude range is from 1·6 to 9·6. However, neither the period nor the magnitude range may be regarded as at all constant; at some maxima the magnitude never exceeds 5. The spectrum is of type Me, and the reddish colour makes *Mira* easy to identify.

IOTA CASSIOPEIÆ. R.A. $2^h\ 25^m{\cdot}9$, Dec. +67° 14′

A triple star. Magnitudes 4·2, 7·0, 8·0, p.a's. 251°, 113°; distances 2″·4, 7″.4. Excellently seen with a moderate telescope.

RHO PERSEI. R.A. $3^h\ 02^m{\cdot}7$, Dec. +38° 42′

An M-type irregular variable, not far from *Algol*. The magnitude range is from 3·4 to 4·1; Kappa Persei (4·0) makes a good comparison star. The reddish hue is well brought out in binoculars.

BETA PERSEI (*Algol*). R.A. $3^h\ 05^m{\cdot}7$, Dec. +40° 49′

The 'Demon Star', the prototype eclipsing binary. Its period is 2·87 days. For most of this time it is of magnitude 2·3; it then drops to 3·5 in five hours, and after minimum takes another five hours to climb back to maximum. *Algol* may be studied with the naked eye, and its apparent fluctuations are interesting to follow.

ETA TAURI (*Alcyone*). R.A. $3^h\ 45^m{\cdot}2$, Dec. +23° 59′

The brightest star in the Pleiades (Seven Sisters), the most

conspicuous open cluster in the sky. Keen-sighted persons will be able to see at least eight Pleiads with the naked eye. The best views of the cluster are obtained with binoculars or very low powers on a telescope. The names of the other leading stars in the Pleiades are *Electra*, *Atlas*, *Merope*, *Maia*, *Taygete*, *Celæno*, *Pleione* and *Asterope*.

ALPHA TAURI (*Aldebaran*). R.A. $4^h\ 33^m{\cdot}7$, Dec. $+16°\ 2'6$

A K-type reddish star of magnitude 0·85. It is 57 light-years distant, and is ninety times as luminous as the Sun. Extending from it in a rough V are the stars of the very loose cluster known as the Hyades; one of these (Theta Tauri) is a naked-eye double. *Aldebaran* has a faint companion (magnitude 11; p.a. 034°, distance 121″). Actually, *Aldebaran* is not a true member of the Hyades group, and lies between the cluster and ourselves.

EPSILON AURIGÆ. R.A. $4^h\ 59^m{\cdot}2$, Dec. $+43°\ 46'$

The leading member of the 'Hædi' or Kids, a triangle of three faint stars close to *Capella*. Epsilon is an eclipsing binary; the magnitude range is from 3·3 to 4·1, and the period is over 27 years. One component is a very luminous F-type supergiant. The fainter star is invisible, and appears to be the largest individual star known, with a diameter of over 1,800 million miles.

ZETA AURIGÆ. R.A. $4^h\ 59^m{\cdot}8$, Dec. $+41°\ 01'$

The faintest member of the 'Hædi'. It too is an eclipsing binary, though it is not so vast a system as Epsilon. The spectral types of the components are K0 and B1. The mean magnitude is 4·0; the fluctuations are not easy to detect without instrumental aid.

KAPPA LEPORIS. R.A. $5^h\ 11^m{\cdot}5$, Dec. $-12°\ 59'$

A double star; magnitudes 5·0, 7·5; p.a. 000°; distance 2″·6. The primary is yellowish; the companion bluish.

BETA ORIONIS (*Rigel*). R.A. $5^h\ 12^m{\cdot}7$, Dec. $-8°\ 15'$

The leading star of Orion; magnitude 0·15. The distance is thought to be about 540 light-years. *Rigel* is exceptionally lumin-

ous, and is the equal of at least 18,000 Suns. It has a B-type spectrum, and is almost pure white There is a seventh-magnitude companion (p.a. 202°, distance 9″·4) easily seen in a 3-inch refractor.

ALPHA AURIGÆ (*Capella*). R.A. 5^h $13^m·9$, Dec. +45° 58′

Magnitude 0·09; spectrum G0. *Capella* is of a yellowish hue, and is a superb object in binoculars. It is an extremely close binary. The distance is 47 light-years, and the luminosity 150 times that of the Sun. Apart from *Arcturus* and *Vega*, it is the brightest star in the northern hemisphere of the sky.

DELTA ORIONIS (*Mintaka*). R.A. 5^h $30^m·1$, Dec. −0° 20′

The upper star of Orion's belt; it lies almost on the celestial equator. The primary is an eclipsing binary of small range; average magnitude 2·4. There is a seventh-magnitude companion (p.a. 000°, distance 52″·8) which is a very easy telescopic object.

MESSIER 1 TAURI. R.A. 5^h $32^m·2$, Dec. + 22° 00′

The 'Crab' Nebula; a fascinating object not far from the third-magnitude star Zeta Tauri. It is the wreck of a supernova which was observed by Chinese astronomers in the year 1054. In a small telescope it appears as a faint, diffuse object; large instruments reveal complex detail. The gas-cloud is still expanding from the old explosion-centre.

MESSIER 42 ORIONIS. R.A. 5^h $33^m·4$, Dec. −5° 25′

In the Sword of Orion; the most prominent gaseous nebula in the sky. It is visible with the naked eye. Excellent views of it are obtained with low powers on small or moderate telescopes. It contains the famous multiple star Theta Orionis, the 'Trapezium' (R.A. 5^h 33^m,, Dec. −5° 27′) whose four components are visible in a 3-inch refractor. This superb nebula is always worth looking at.

IOTA ORIONIS. R.A. 5^h $33^m·6$, Dec. −5° 56′

A double star. Magnitudes 3·2, 7·3; p.a. 141°; distance 11″·4. This is the lowest star of Orion's Sword.

SIGMA ORIONIS. R.A. $5^h\ 36^m{\cdot}8$, Dec. $+2°\ 37'$

Another fine multiple in Orion's Sword. Four stars (magnitudes 4, 10, 7·5, 7) are fairly easy to see with a moderate telescope; larger instruments reveal several more.

ZETA ORIONIS. R.A. $5^h\ 38^m{\cdot}8$, Dec. $-1°\ 58'$

The lowest star of Orion's Belt. The 2·0-magnitude, B-type primary has a 5·0-magnitude companion; p.a. 157°, distance 2″·8. This is a well-known test for a 2-inch refractor.

ALPHA ORIONIS (*Betelgeuse*). R.A. $5^h\ 53^m{\cdot}1$, Dec. $+7°\ 24'$

A particularly interesting star. It is an M0-type supergiant, 1,200 times as luminous as the Sun, and 192 light-years away. The diameter is about 250 million miles, but this changes somewhat, as the star is an irregular variable. There is a rough period of about five years. The magnitude range is from 0·1 to 1·3. On very rare occasions *Betelgeuse* has been known to outshine *Rigel*. Its orange-red hue makes it a superb sight in binoculars or a low power.

MESSIER 35 GEMINORUM. R.A. $6^h\ 06^m{\cdot}5$, Dec. $+24°\ 20'$

A splendid open cluster near Mu and Eta Geminorum. This is one of the most spectacular cluster-type objects visible with small telescopes.

ETA GEMINORUM. R.A. $6^h\ 12^m{\cdot}6$, Dec. $+22°\ 31'$

A long-period variable; period 231 days, range 3·3 to 4·2. The spectrum is of type M, and the colour orange-red. The neighbouring star Mu, magnitude 3·2 and also of type M, makes a good comparison. The variations of Eta are slow, but may be followed with the naked eye.

BETA MONOCEROTIS. R.A. $6^h\ 27^m{\cdot}0$, Dec. $-7°\ 00'$

A triple star. Magnitudes 5·0, 5·5, 6·0; p.a. 132°, 105°, distances 7″·4, 2″·8. A fine sight in a moderate telescope.

H.VII. 2 MONOCEROTIS. R.A. $6^h\ 30^m{\cdot}3$, Dec. $+4°\ 54'$

A beautiful open cluster just visible to the naked eye.

ALPHA CANIS MAJORIS (*Sirius*). R.A. $6^h\ 43^m{\cdot}5$, Dec. $-16°\ 40'$

The brightest star in the sky. It is of magnitude $-1{\cdot}43$, and has an A0-type spectrum; it is 26 times as luminous as the Sun, and is one of the closest of all stars, since its distance is only 8·6 light-years. It is a wonderful sight in binoculars. The famous companion, Sirius B, is a white dwarf, but unfortunately invisible except in large telescopes.

MESSIER 41 CANIS MAJORIS. R.A. $6^h\ 45^m{\cdot}4$, Dec. $-20°\ 42'$

An open cluster, just visible to the naked eye and excellently seen with low powers.

ZETA GEMINORUM. R.A. $7^h\ 01^m{\cdot}9$, Dec. $+20°\ 38'$

A cepheid variable. Its magnitude range is from 3·7 to 4·3, and its period is 10·2 days. Nu Geminorum (magnitude 4·1) is a useful comparison star. Zeta has a G-type spectrum, and is rather yellowish.

ALPHA GEMINORUM (*Castor*). R.A. $7^h\ 32^m{\cdot}2$, Dec. $+31°\ 58'$

The senior though fainter of the famous 'Twins'. It was ranked of the first magnitude by the old astronomers, but is now appreciably below; its magnitude is 1·6. It is a fine binary, with a period of 350 years; p.a. 204°, distance 4″. The individual magnitudes of the two components are 2·0 and 2·8. Each is a spectroscopic binary, and the faint eclipsing binary YY Geminorum (=Castor C) is also a member of the system.

BETA GEMINORUM (*Pollux*). R.A. $7^h\ 43^m{\cdot}0$, Dec. $+28°\ 07'$

The orange hue of *Pollux* (spectrum K0) contrasts with the pure white of *Castor*. The magnitude is 1·2, the distance 32 light-years, and the luminosity 28 times that of the Sun.

MESSIER 44 CANCRI. R.A. $8^h\ 38^m$, Dec. $+20°\ 07'$

Præsepe, or the 'Beehive', is a fine open cluster. It is easily

visible to the naked eye on a moonless night, close to the two faint stars Delta and Gamma Cancri. It is well seen with low powers, and is not difficult to resolve into separate stars.

ALPHA HYDRÆ (*Alphard*). R.A. $9^h\ 25^m{\cdot}7$, Dec. $-8°\ 30'$

Alphard, the 'Solitary One', is easy to locate; it lies more or less in line with *Castor* and *Pollux*, and is very isolated. Moreover it is of type K, and decidedly red. *Alphard* is a spectacular object when viewed with binoculars.

GAMMA LEONIS. R.A. $10^h\ 17^m{\cdot}9$, Dec. $+20°\ 02'$

A binary with a period of 407 years. The magnitudes are 2·4 and 3·8; the p.a. 119°, and the distance 4″. The star is easy to identify, as it lies in the famous Sickle of Leo, not far from *Regulus*. It is a fine sight in a moderate telescope.

U HYDRÆ. R.A. $10^h\ 35^m{\cdot}7$, Dec. $-13°\ 11'$

An N-type irregular variable, with a range from magnitude 4·5 to 6. It is the brightest of the stars of spectrum N, and its deep-red colour makes it of great interest.

MESSIER 97 URSÆ MAJORIS. R.A. $11^h\ 12^m{\cdot}6$, Dec. $+55°\ 13'$

The 'Owl' nebula. It is 3′ in diameter, and is one of the interesting objects known as planetary nebulæ. It is not, however, very conspicuous, and will hardly be seen in a small telescope.

GAMMA VIRGINIS. R.A. $12^h\ 39^m{\cdot}7$, Dec. $-1°\ 14'$

One of the most spectacular binaries in the sky. Each component is of type F0, and the magnitudes are almost equal at 3·6. The period is 180 years, and the separation is becoming steadily less, but it is still well over 5″, so that the components are excellently seen in a small telescope.

ALPHA CANUM VENATICORUM (*Cor Caroli*). R.A. $12^h\ 54^m{\cdot}3$, Dec. $+38°\ 31'$

An easy double. Magnitudes 3·1, 5·6; p.a. 228°; distance 19″·7.

ZETA URSÆ MAJORIS (*Mizar*). R.A. $13^h\ 22^m{\cdot}4$, Dec. $+55°\ 07'$

The second star in the Plough-handle. It forms a naked eye pair with *Alcor* (magnitude 5). *Mizar* is itself a binary; magnitudes 2·2, 4·2; p.a. 150°, distance 14″·5. In any small telescope the components are easily separated. With low powers *Alcor* also is in the field, and between it and *Mizar* is yet another star. This is one of the best binary objects for small apertures, particularly as *Mizar* is so easy to locate.

MESSIER 3 CANUM VENATICORUM. R.A. $13^h\ 40^m{\cdot}4$, Dec. $+28°\ 34'$

A bright globular cluster on the borders of Canes Venatici and Boötes. With a moderate telescope, the cluster is fully resolvable into stars.

ALPHA BOÖTIS (*Arcturus*). R.A. $14^h\ 13^m{\cdot}9$, Dec. $+19°\ 23'$

Apart from *Sirius*, *Arcturus* is the brightest star visible from the latitude of Britain. Its magnitude is −0·06, its distance 41 light-years, and its luminosity 100 times that of the Sun. The spectrum is of type K, and *Arcturus*' glorious orange hue makes it a fine sight with binoculars or a low power.

EPSILON BOÖTIS. R.A. $14^h\ 43^m{\cdot}3$, Dec. $+27°\ 14'$

A third-magnitude star with a sixth-magnitude companion at distance 2″·8, p.a. 335°. The primary is yellowish, the companion bluish.

R CORONÆ BOREALIS. R.A. $15^h\ 47^m{\cdot}0$, Dec. $+28°\ 16'$

A curious irregular variable. For long periods the magnitude remains at 6, and then drops suddenly, sometimes to below 12. After a period of minimum brilliancy, which may be protracted, the star rises once more to magnitude 6. The causes of this behaviour are unknown, and amateur observers can do valuable work by studying R Coronæ and other stars of its type.

T CORONÆ BOREALIS. R.A. $15^h\ 57^m{\cdot}9$, Dec. $+26°\ 02'$

The 'Blaze Star'. Normally it is of below magnitude 8, but it has

suffered two major outbursts – one in 1866 (magnitude 2) and the other in 1946 (magnitude 4). Minor fluctuations are always going on, and the star merits close attention from amateur observers.

BETA SCORPIONIS. R.A. $16^h\ 03^m{\cdot}2$, Dec. $-19°\ 42'$

Magnitudes 3·0, 5·2; p.a. 023°; distance 14″. This is a wide, easy double.

MESSIER 80 SCORPIONIS. R.A. $16^h\ 14^m{\cdot}8$, Dec. $-22°\ 53'$

A bright globular cluster between *Antares* and Beta Scorpionis. Well seen in a moderate telescope.

MESSIER 4 SCORPIONIS. R.A. $16^h\ 21^m{\cdot}3$, Dec. $+26°\ 26'$

An open cluster, close to *Antares*. The diameter is about 14′, and the whole cluster is easily resolvable.

ETA DRACONIS. R.A. $16^h\ 23^m{\cdot}5$, Dec. $+61°\ 36'$

A G5-type star of magnitude 2·9, with an eighth-magnitude companion at p.a. 142°, distance 6″·1. It is a test for a 3-inch refractor.

ALPHA SCORPIONIS (*Antares*). R.A. $16^h\ 27^m{\cdot}1$. Dec. $-26°\ 21'$

The 'Rival of Mars'. *Antares* is an M-type supergiant, 3,400 times as luminous as the Sun, and 360 light-years away. It is strongly red in hue, and has a seventh-magnitude greenish companion at p.a. 275°, distance 3″. For some time *Antares* was believed to be the largest star known; though it is in fact surpassed by others, it is still of exceptional size. It is unfortunate that it never rises very high over the British horizon.

ZETA HERCULIS. R.A. $16^h\ 39^m{\cdot}9$, Dec. $+31°\ 40'$

A splendid binary with a period of 34 years. The distance reached 1″·6 in 1954, and is now decreasing. The primary is a star of spectral type G0, magnitude 3; the companion is of magnitude 6·5.

MESSIER 13 HERCULIS. R.A. $16^h\ 40^m$, Dec. $+36°\ 32'$

The brightest of the globular clusters visible from the latitude

of Britain. It may be seen with the naked eye on a clear night, and lies between Zeta and Eta Herculis, considerably closer to Eta. With a moderate telescope, it is fully resolvable, and is a magnificent sight, but in very small instruments it is somewhat disappointing.

ALPHA HERCULIS. R.A. $17^h\ 12^m{\cdot}9$, Dec. $+14°\ 26'$

One of the most interesting stars in the sky. The primary is an M-type supergiant, variable between magnitudes 3 and 3·7 in an irregular manner; it has the distinction of being one of the largest stars known. The companion (magnitude 6, p.a. 112°, distance 4″·5) is distinctly green. In a moderate telescope the colours make a superb contrast. The fluctuations of the primary may be followed with the naked eye; Kappa Ophiuchi (magnitude 3·4) makes a useful comparison star.

MESSIER 92 HERCULIS. R.A. $17^h\ 16^m{\cdot}0$, Dec. $+43°\ 11'$

A globular cluster between Eta and Iota Herculis. It resembles M13, but is much less conspicuous.

MESSIER 7 SCORPIONIS. R.A. $17^h\ 51^m{\cdot}5$, Dec. $-34°\ 49'$

A magnificent open cluster near the Scorpion's 'sting'. Unfortunately it is never well seen in Britain, as it is always low in the sky.

MESSIER 23 SAGITTARII. R.A. $17^h\ 54^m{\cdot}7$, Dec. $-19°\ 01'$

An open cluster almost 50′ in diameter, well seen with a low power.

H.IV. 37 DRACONIS. R.A. $17^h\ 58^m{\cdot}6$, Dec. $+66°\ 38'$

One of the brightest of the planetary nebulæ. It is well seen with a moderate telescope.

MESSIER 8 SAGITTARII. R.A. $18^h\ 01^m{\cdot}3$, Dec. $-24°\ 23'$

The 'Lagoon' nebula. This is a gaseous nebula, and is contained in our own Galaxy. It is faintly visible with the naked eye, and moderate telescopes show a large amount of detail; there are

bright patches and dark rifts. This whole area is rich in nebular objects, and is well worth sweeping.

N.G.C. 6572 OPHIUCHI. R.A. $18^h\ 10^m{\cdot}2$, Dec $+6°\ 50'$

A small, bright planetary nebula, lying between Beta Ophiuchi and Zeta Aquilæ. It is an easy object in a small telescope.

MESSIER 17 SAGITTARII. R.A. $18^h\ 18^m{\cdot}6$, Dec. $-16°\ 12'$

The 'Omega' nebula. The nearest naked-eye star is Gamma Scuti. Like the Lagoon, this is a gaseous nebula contained in our own Galaxy, and is large and bright, with abundant detail.

ALPHÆ LYRÆ (*Vega*). R.A. $18^h\ 35^m{\cdot}7$, Dec. $+38°\ 45'$

Vega is the brightest star in the northern hemisphere of the sky, apart from *Arcturus*. Its magnitude is 0·0, its spectral type A0, its distance 26 light-years and its luminosity 50 times that of the Sun. It is notable because of the distinctly bluish cast which makes it a superb object in low powers. It has a companion of magnitude 10·5, at p.a. 170°, distance 56″. This is an optical pair, and not a binary; the companion is faint and moreover overpowered by the brilliance of the primary, so that it is not a particularly easy object. *Vega* is very high up during summer evenings, and cannot be mistaken.

EPSILON LYRÆ. R.A. $18^h\ 43^m{\cdot}1$, Dec. $+39°\ 34'$

A fascinating quadruple star. Epsilon^1 and Epsilon^2 form a naked-eye pair (distance 208″), and are easy to find, since they lie near *Vega*. Each is again double; Epsilon^1 (magnitudes 4·6, 6·3; p.a. 005°; distance 3″) and Epsilon^2 (4·9, 5·2; 111°; 2″·3) and there are various other stars in the same low-power field. This is a particularly good object for viewing with a small or moderate telescope.

ZETA LYRÆ. R.A. $18^h\ 43^m{\cdot}5$, Dec. $+37°\ 34'$

A wide, easy double. Magnitudes 4·2, 5·5; p.a. 150°; distance 44″.

BETA LYRÆ. R.A. $18^h\ 48^m{\cdot}7$, Dec. $+33°\ 19'$

The prototype 'ellipsoidal' variable. It is not in fact a true

Biographical Notes on Contributors

DR J. G. PORTER was for many years concerned with the production of the *Nautical Almanac*, and retired from the Royal Greenwich Observatory in 1961; he is now carrying out research in the United States. In addition to his computing work, he has specialized in the study of comets and meteors, and is the author of *Comets and Meteor Streams*. He is a Past President of the British Astronomical Association, and former Director of its Computing Section. For over ten years he made monthly broadcasts on astronomical subjects.

PATRICK MOORE is an amateur astronomer who carries out lunar and planetary observations from his private observatory in Sussex. He is Director of the Mercury and Venus Section of the British Astronomical Association, author of a number of astronomical books and a regular broadcaster.

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DR R. C. JENNISON is Senior Lecturer in Radio Astronomy at Manchester University and has been actively engaged in Radio Astronomy at Jodrell Bank since 1950. In late 1959 he formed a satellite and rocket instrumentation group at Manchester and has a number of radio astronomy and micrometeorite experiments in current space vehicles.

DR A. H. JARRETT is Lecturer in Astronomy at The Queen's University of Belfast, and leader of a group working on rocket investigations of the upper atmosphere. During an

appointment as Lecturer in Astronomy at St Andrews University he was actively concerned with auroral and airglow research.

DR R. GRIFFIN is at present working at Mount Wilson and Palomar Observatories as a Carnegie Institution Postdoctoral Fellow. While researching on astrophysics at Cambridge Observatories he developed new equipment to make photoelectric measurements on stellar spectra. He is a Fellow of the Royal Astronomical Society.

B. M. PEEK is the author of *The Planet Jupiter* and his main work has been both observation and theoretical work on that planet. He is a past President of the British Astronomical Association.

D. A. CAMPBELL is by profession an Experimental Officer at the Post Office Research Station, and an amateur astronomer who has constructed many of his own instruments. From 1935–50 he specialized in meteor observation both visual and photographic, working with the team of observers under the Director of the Meteor Section of the British Astronomical Association. He is Vice-President of the Association.

J. C. VETTERLEIN joined the British Astronomical Association's Computing Section in 1952, in which he worked on cometary ephemerides and related problems. In 1955 he took up the serious study of double stars and has made extensive investigations into most aspects of his subject. His contributions include papers, and measures of visual double stars.

PHILIP S. LAURIE is a Senior Experimental Officer at the Royal Greenwich Observatory, Herstmonceux, which he joined in 1935. He supervises the Solar Department, whose principal work is the detailed measurement and publication of the positions and areas of sunspots.

DR H. R. CALVERT studied physics at Oxford under Lindemann and later at Göttingen, Germany. After working as a research physicist in industry he went to the Science Museum, South Kensington in 1934, where he now has charge of the Astronomy Department.

variable, but is an eclipsing binary of special type. The maximum is magnitude 3·4; the minima are alternately of magnitude 3·8 and 4·1; the period is 12·9 days. Gamma Lyræ (magnitude 3·3) is a useful comparison star. The system of Beta Lyræ is of particular interest from an astrophysical point of view. The spectra are B8 and B2, but each is peculiar, and the components are too close to be separated visually.

MESSIER 11 SCUTI. R.A. $18^h\ 49^m{\cdot}0$, Dec. $-6°\ 19'$

The 'Wild Duck'. A superb open cluster, not far from Lambda Aquilæ. It is faintly visible to the naked eye. A moderate telescope shows it as a fan-shaped cluster, with a bright star at its apex.

MESSIER 57 LYRÆ. R.A. $18^h\ 52^m{\cdot}2$, Dec. $+32°\ 49'$

The 'Ring' nebula. This is the most famous of the nebulæ, and is extremely easy to find, as it lies between Beta and Gamma Lyræ. In a small telescope it does indeed look like a ring; the dark centre is easy to see, but the central star is a difficult object.

THETA SERPENTIS. R.A. $18^h\ 54^m{\cdot}3$, Dec. $+4°\ 09'$

One of the best double stars for a small telescope. The components are almost equal at magnitude 4·1; the p.a. is 103°, and the distance $22''{\cdot}3$. The star is easy to find, as it lies almost in a line with Theta, Eta and Delta Aquilæ. Each component is white.

BETA CYGNI. R.A. $19^h\ 29^m{\cdot}2$, Dec. $+27°\ 53'$

Beta Cygni (*Albireo*) is probably the loveliest double star in the sky. It is an easy object; the magnitudes are 3·0 and 5·3, the p.a. 055°, and the separation $35''$, so that any small telescope will show it. The contrasting colours make it striking; the primary is yellow, while the companion is strongly bluish-green. *Albireo* appears the faintest of the five stars which make up the cross of Cygnus, but it is in fact a very luminous star lying at a great distance from us.

CHI CYGNI. R.A. $19^h\ 49^m{\cdot}1$, Dec. $+32°\ 49'$

An M-type long-period variable. The range is from magnitude

4 to 14, and the period 409 days; it is the *Mira* type. When near maximum it is easily visible to the naked eye, and may be compared with its near neighbour Eta Cygni (magnitude 4). Near minimum, a powerful telescope is needed to show it.

ETA AQUILÆ. R.A. $19^h\ 50^m{\cdot}5$, Dec. $+0°\ 54'$

Spectrum G0 (peculiar). Eta is a typical cepheid variable, with a range from magnitude 3·7 to 4·5, and a period of 7·18 days. It lies between Delta (magnitude 3·4) and Theta (also 3·4), which are useful as comparison stars.

MESSIER 27 VULPECULÆ. R.A. $19^h\ 57^m{\cdot}9$, Dec. $+22°\ 37'$

The curious galactic 'Dumb-bell' nebula, not far from Gamma Sagittæ. It is a faint object in a small telescope, but is well worth looking for.

ALPHA CAPRICORNI. R.A. $20^h\ 15^m{\cdot}7$, Dec. $-12°\ 39'$

A naked-eye double; Alpha^1 and Alpha^2, of magnitudes 3·7 and 4·3 respectively, are separated by 378″. Alpha^1 has a ninth-magnitude companion at 45″. Alpha^2 is itself a difficult double; the companion is of magnitude 11, position angle 158°, distance 7″. Since the faint companion is a close binary, the whole system is decidedly complex.

ALPHA CYGNI (*Deneb*). R.A. $20^h\ 40^m{\cdot}1$, Dec. $+45°\ 09'$

The brightest star of Cygnus. It is of magnitude 1·3, and has a peculiar A2-type spectrum. It is an exceptionally luminous star, at least 10,000 times as brilliant as the Sun, and is of great interest to astrophysicists. Its yellowish colour is well shown by use of a low power.

GAMMA DELPHINI. R.A. $20^h\ 44^m{\cdot}9$, Dec. $+15°\ 29'$

A wide, easy double. Magnitudes 4, 5; p.a. 270°, distance 10″·4. The primary is yellowish, the companion greenish.

H.IV. 1 AQUARII. R.A. $21^h\ 02^m{\cdot}1$, Dec. $-11°\ 31'$

A bright planetary nebula, known as the Saturn nebula for

reasons which will be obvious when the object is studied with a large aperture. In smaller telescopes the Saturn-like appearance is not seen, but nevertheless the nebula is a most interesting object. It lies near the fourth-magnitude star Nu Aquarii.

61 CYGNI. R.A. $21^h\ 05^m{\cdot}2$, Dec. $+38°\ 33'$

An easy binary; magnitudes 5·3, 5·9; p.a. 134°; distance 25″. 61 Cygni is famous as being the first star to have its distance measured – by Bessel, in 1838. The system is about 11 light-years away. Both components are dwarfs, and the fainter (B) is suspected to have a large planet associated with it.

MESSIER 15 PEGASI. R.A. $21^h\ 28^m{\cdot}1$, Dec. $+12°\ 00'$

A splendid globular cluster not far from Epsilon Pegasi (magnitude 2·5). A small telescope will show it well.

BETA CEPHEI. R.A. $21^h\ 28^m{\cdot}2$, Dec. $+70°\ 24'$

A third-magnitude star with an eighth-magnitude companion at p.a. 250°, distance 13″·7. As it is circumpolar, it makes a useful test (for small apertures) which is available on any clear night.

MESSIER 39 CYGNI. R.A. $21^h\ 30^m{\cdot}9$, Dec. $+48°\ 16'$

A large open cluster, between *Deneb* and Alpha Lacertæ, well seen with low powers.

MU CEPHEI. R.A. $21^h\ 42^m{\cdot}3$, Dec. $+58°\ 36'$

The 'Garnet Star' of Sir William Herschel. It is a *Betelgeuse* type irregular variable, but since its fluctuations lie between magnitudes 4 and 6 it is never brilliant. However, any optical aid will bring out its lovely red colour; it has been compared with a glowing coal.

DELTA CEPHEI. R.A. $22^h\ 27^m{\cdot}8$, Dec. $+58°\ 13'$

The prototype cepheid. It changes between magnitudes 3·7 and 4·3 in a period of 5·37 days. Its neighbour Zeta (magnitude 3·6) makes a useful comparison star.

ALPHA PISCIS AUSTRINI (*Fomalhaut*). R.A. $22^h\ 55^m{\cdot}6$, Dec. $-29°\ 49'$

This is the southernmost of the first-magnitude stars visible from Britain. It can be quite conspicuous from southern England, but from northern Scotland it is always extremely low down. It is of spectrum A3, and is 13 times as luminous as the Sun. As it lies at a distance of only 24 light-years, it is the nearest of the first-magnitude stars apart from *Sirius*, *Procyon* and *Alpha Centauri*.

BETA PEGASI. R.A. $23^h\ 01^m{\cdot}9$, Dec. $+27°\ 53'$

An M-type variable of the *Betelgeuse* class. Its range is between magnitudes 2·3 and 2·8, and there is a very rough period of about five weeks. It is one of the stars making up the Square of Pegasus, and good comparisons are Alpha Pegasi (2·6) and Gamma (2·9). Beta is strongly orange in hue, and its alterations in brightness may be followed with the naked eye. Incidentally, it is instructive to select a clear night and then count the number of naked-eye stars contained in the Square of Pegasus. There are not very many of them!

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Edited by J. G. Porter Associate Editor Patrick Moore

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